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EFFECT OF APPLICATIONS OF FINE LIMESTONE: III. THE YIELD AND NITROGEN CONTENT OF INOCULATED AND NON-INOCULATED ALFALFA GROWN ON SHELBY LOAM[1]

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THE effects of limestone on the growth and nodulation of legumes are varied and complex. It is thought by some investigators that the main function of calcium in plant growth is that of neutralizing the soil acidity, whereas others are of the opinion that the most important rôle played by calcium is that of a plant nutrient.

Many investigators (7, 8, 17, 19, 20, 22)[3] have reported beneficial effects due to liming and inoculation of legumes. Walker and Brown (21) obtained results showing that certain legume bacteria in the soil are favorably influenced by the application of limestone.

Albrecht and Davis (2) found that where small amounts of calcium were used soybeans were readily attacked by disease and only poor growth occurred, while with increased amounts of calcium, growth improved and seemed to be normal, but only as still greater amounts of calcium were available to the plant would nodulation occur. Allison and Ludwig (4) suggested that nodule formation will not occur unless there is present a rapid growth of root tissue and that factors retarding rapid root growth also retard nodulation. Truog (18) observed that roots of alfalfa plants grown in acid soils may not be infected even though there are present large numbers of the desired legume bacteria in the soil.

Nodulation and plant growth of legumes have been studied by various investigators when a part of the roots were grown in acid soils and a part in limed soils. Karraker (10) noted that the effect of soil reaction on alfalfa is localized and affects only that part of the roots directly in contact with the acid soil. Albrecht and Davis (3) and Doolas (6) obtained similar results by growing soybeans in the greenhouse with the roots extending partially through acid zones of soil ranging in

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[3]Figures in parenthesis refer to "Literature Cited", p. 8.

pH from 3.8 to 5.6. Distinct differences in the plant cell wall structure of soybean seedlings were noted in the micro-sections made of calcium-starved seedlings and those grown on soil containing calcium.

Upon adding calcium acetate to Gray silt loam and Bates fine sandy loam, both acid soils, Scanlan (15) secured very little change in acidity, but the nodulation of soybeans increased 1,000%. In a similar experiment on Putnam silt loam nodulation was increased 433%.

From a series of experiments, Sewell and Gainey (16) concluded that the reaction of the soil, if within a range of pH 4.5 to 7.0, is a minor factor in the growth of alfalfa, providing all of the needed nutrients are supplied.

According to Crist and Weaver (5), nutrients, when available, are taken from the deeper soil layers in large quantities which may produce pronounced effects upon the quantity and quality of the crop yield.

Previous investigations (1, 11, 12, 13, 14) have shown quite clearly that some legumes may be satisfactorily grown on acid soils where small amounts of fine limestone are applied in the row with the seed. Since this method is practiced, it would be of value to know whether legumes grown in this manner fix as much nitrogen as those grown in fully neutralized soils. This experiment was designed and a greenhouse and laboratory study made of the effects of fine limestone in the row and beside the row on the nitrogen content of inoculated and non-inoculated alfalfa plants grown on Shelby loam.

EXPERIMENTAL

The surface soil of a Shelby loam, having a pH of 5.40, a lime requirement (9) of 3.0 tons per acre, and a total nitrogen content of 3,270 pounds per acre, was employed in this experiment. The fine limestone used, which passed a 100-mesh sieve, was 95.5% $CaCO_3$.

The soil was air dried and screened through a ¼ inch sieve. Thirty-four pounds of air-dry soil were placed into each of 24 4-gallon earthenware pots. The treatments were made in triplicate and a 20% superphosphate was applied broadcast to the upper 7 inches of soil in all of the pots. The soils receiving 6,015 pounds of fine limestone per acre applied broadcast were also treated at this time. Two weeks elapsed from the time of potting the soil to the time of planting. Alfalfa was seeded in two rows, 5 inches apart and 10 inches long across each pot. The pots were arranged in the greenhouse according to a randomization procedure and the pots were re-randomized once every two weeks throughout the experiment. Artificial lights were employed about 8 hours each day throughout the winter months.

The method of applying fine limestone beside the row was to apply one-half of the desired amount ½ inch on each side of the row at the same depth as the seed. All seeds were sown ⅔ inch deep and the growth in all pots thinned down to 12 plants per pot.

An outline of the treatment is given in Table 1.

A stock culture of an efficient strain of *Rhizobium meliloti* was used to inoculate the alfalfa used in the inoculated series. The seeds were inoculated at the time of seeding and dusted with a mercury dust. One hundred twenty days after planting, the tops and roots of the plants were harvested separately, dried, weighed, ground, and analyzed for total nitrogen by the Kjeldahl method. The data secured were analyzed statistically according to the method of analysis of variance.

TABLE 1.—*Outline of treatments.*

Treatment per acre	Inoculated pot No.	Non-inoculated pot No.
None	A-B-C	A-B-C
500 pounds fine limestone applied in row	A-B-C	A-B-C
500 pounds fine limestone applied beside the row	A-B-C	A-B-C
6,015 pounds fine limestone applied broadcast	A-B-C	A-B-C

RESULTS

In the inoculated series it was noticed at the time of harvest that about 85% of the roots of the plants grown on the untreated soils were inoculated, whereas in the non-inoculated series about 25% of the plants were inoculated. The roots of the plants grown on the soils receiving limestone were 100% inoculated in the inoculated series. The plants grown on the fully limed soils in the inoculated series contained many more nodules than those grown on the other treated soils. In the non-inoculated series about 17% of the plants were inoculated where limestone was applied beside the row, 40% where limestone was applied in the row, while approximately 55% of the plants grown on the fully limed soils were inoculated. In all cases only very few nodules per plant were found on those plants which were inoculated in the non-inoculated series. The fact that a great many of the plants in the non-inoculated series were inoculated must be taken into consideration in evaluating the results of this experiment.

No nodules were observed on the tap roots of any of the plants. This may have been due to the mercury dust used to control the "damping-off" organism. The use of this mercury dust might also account for the small difference between the weights of the inoculated and non-inoculated plants. In the inoculated series a concentration of nodules on the root hairs was observed in the limed zone where the fine limestone was applied in the row.

The pH determinations of the soil at the time of harvest are given in Table 2. The results in this experiment were similar to those obtained in the previous experiments (11, 12) in that it was found that the limestone applied in the row did not neutralize the second inch of soil to any appreciable extent.

YIELD AND NITROGEN CONTENT OF INOCULATED AND NON-INOCULATED ALFALFA

The yield and nitrogen content of the inoculated and non-inoculated alfalfa are shown in Table 3. An analysis of variance was also made on the yield and nitrogen content of the plants and the results are given in Table 4.

The analysis of variance of the total dry weight and total nitrogen content showed a highly significant difference between the inoculated and non-inoculated alfalfa. The inoculated plants weighed more and contained more nitrogen than the uninoculated plants. A highly significant difference was found to exist between the total dry weight an total nitrogen content of alfalfa grown on soil receiving limestone i

TABLE 2.—*The pH of soils at the time of harvesting inoculated and non-inoculated alfalfa grown on Shelby loam.**

Region of sampling	Block	Inoculated, pH	Non-inoculated, pH
No Treatment			
In the row 0 to 1 in. deep	A	5.46	5.50
	B	5.49	5.45
	C	5.50	5.50
Mean		5.48	5.49
In the row 1 to 2 in. deep	A	5.49	5.46
	B	5.48	5.45
	C	5.46	5.48
Mean		5.48	5.47
500 lbs. Fine Limestone in the Row			
In the row 0 to 1 in. deep	A	6.73	6.84
	B	6.74	6.76
	C	6.81	6.86
Mean		6.76	6.82
In the row 1 to 2 in. deep	A	5.51	5.59
	B	5.54	5.56
	C	5.51	5.57
Mean		5.52	5.57
500 lbs. Fine Limestone Beside the Row			
In the row 0 to 1 in. deep	A	6.52	6.42
	B	6.57	6.36
	C	6.63	6.39
Mean		6.57	6.39
In the row 1 to 2 in. deep	A	5.56	5.58
	B	5.54	5.48
	C	5.50	5.54
Mean		5.54	5.53
6,015 lbs. Fine Limestone Applied Broadcast			
In the row 0 to 1 in. deep	A	7.26	7.35
	B	7.30	7.43
	C	7.40	7.45
Mean		7.32	7.41
In the row 1 to 2 in. deep	A	7.28	7.38
	B	7.41	7.38
	C	7.45	7.48
Mean		7.38	7.41

*The pH determination of soil at beginning of experiment was 5.40.

the row in comparison with the alfalfa grown on the untreated soil. No significant difference was found in the total dry weight or total

TABLE 3.—*The yield and nitrogen content of inoculated and non-inoculated alfalfa grown on Shelby loam.*

Inoculated								Non-inoculated							
Tops			Roots			Total plant		Tops			Roots			Total plant	
Dry* weight, grams	N, %	Total, N, mgms	Dry weight, grams	N, %	Total, N, mgms	Total weight, grams	Total, N, mgms	Dry weight, grams	N, %	Total N, mgms	Dry weight, grams	N, %	Total N, mgms	Total weight, grams	Total N, mgms
No Treatment															
8.0	3.02	251.6	5.8	1.81	105.6	13.8	347.2	7.4	3.07	227.2	4.0	1.73	69.6	11.4	296.8
8.3	3.01	250.7	5.3	1.85	98.6	13.3	349.3	7.0	2.91	204.4	4.8	1.64	79.2	11.8	283.6
8.5	3.05	259.3	5.6	1.74	98.0	14.1	357.3	7.5	2.95	221.3	4.0	1.87	74.8	11.5	296.1
8.3	3.03	250.5	5.6	1.81	100.7	13.7	351.3	7.3	2.98	217.6	4.3	1.75	74.5	11.6	292.2
500 lbs. Fine Limestone in Row															
8.4	3.35	281.4	7.0	1.93	135.8	15.4	417.2	7.6	3.53	268.3	6.0	2.02	121.2	13.6	389.5
10.4	3.32	345.3	6.5	2.01	130.7	16.9	476.0	8.0	3.44	276.0	6.3	1.84	116.6	14.3	392.6
9.5	3.43	326.8	6.4	2.12	135.7	15.9	462.5	8.3	3.56	296.3	5.3	2.14	113.4	13.6	409.7
9.4	3.33	317.8	6.5	2.02	134.0	16.1	451.9	8.0	3.52	280.2	5.9	2.00	117.0	13.8	397.3
500 lbs. Fine Limestone Beside Row															
8.5	3.41	289.9	5.1	2.03	103.5	13.6	393.4	8.1	3.25	263.3	7.4	1.87	138.4	15.5	401.7
8.0	3.41	273.6	6.1	1.98	120.8	14.1	394.4	8.4	3.26	274.7	6.5	2.05	133.9	14.9	408.6
8.6	3.56	306.2	6.1	2.19	134.8	14.7	440.4	7.1	3.17	225.8	6.4	1.93	124.2	13.5	350.0
8.4	3.43	289.9	5.7	2.07	119.5	14.5	409.4	7.9	3.23	254.6	6.8	1.95	132.1	14.6	386.8
6,015 lbs. Fine Limestone Applied Broadcast															
10.0	3.62	362.0	6.0	2.34	141.0	16.0	503.0	8.0	3.41	272.8	6.0	2.26	136.2	14.0	409.0
10.5	3.68	387.5	6.1	2.34	143.4	16.6	530.9	10.5	3.51	369.6	5.1	2.26	115.3	15.6	484.9
11.5	3.52	404.8	6.8	2.27	155.0	18.3	559.8	8.3	3.53	295.5	7.5	2.12	159.8	15.8	455.3
10.7	3.61	384.7	6.3	2.33	146.4	16.9	531.2	8.9	3.49	312.6	6.2	2.22	137.1	15.1	449.7

*dry weight (5% moisture).

TABLE 4.—*Analysis of variance of the dry weight and nitrogen content of inoculated and non-inoculated alfalfa grown on Shelby loam.*

Source of variation	Degrees of freedom	Mean square: Tops, Dry weight	Tops, Total N	Roots, Dry weight	Roots, Total N	Total plant, Dry weight	Total plant, Total N
Between blocks	2	.80	961.7	.06	110.12	.71	117.82
Between inoculation	1	8.16†	13.532 7†	3.78†	597.00	12.32†	17,779.7†
Between treatment							
L_r–L_s	1	1.02	2,148.0	.083	.23	.96	2,106.75
$2L_f$–L_r–L_s	1	7.74†	13,026.4†	.027	134.69	7.65†	25,058.89†
$3L_o$–L_r–L_s–L_f	1	5.33†	22,411.9†	8.06†	8,486.87†	27.62†	60,552.0†
Inoculation × treatment	3	.56	900.7	.38	412.81	2.54*	882.83
Error	14	.473	791.8	.404	177.99	.570	721.37
Total	23	1.39	2,905.67	.820	572.58	2.85	5.152.2
L_s–L_o	1	.333	17.495.60†	—	—	9.01†	4,370.08*
L_r–L_o	1	2 52*	31.744.65†	—	—	15.87†	12.649.01†

*Significant.
†Highly significant.
L_o = No treatment.
L_r = 500 pounds fine limestone in the row.
L_s = 500 pounds fine limestone beside the row.
L_f = 6,015 pounds fine limestone applied broadcast.

nitrogen content of the plants grown on soils receiving limestone in the row and those on soils receiving limestone beside the row. The plants grown on soils treated with limestone, regardless of the method of application, were highly significantly larger and contained more nitrogen than the plants grown on the unlimed soils. The analysis further shows that the total dry weight and total nitrogen content of the plants grown on fully limed soils were highly significantly greater than in the case of the plants grown on the soils receiving limestone in the row or beside the row. With the roots alone, however, the difference was not significant. The relatively small interaction mean square (inoculation × treatment) indicates that the nitrogen content of the alfalfa grown on the variously limed soils varied similarly irrespective of degree of inoculation.

THE INOCULATED SERIES

There was very little difference between the dry weight of alfalfa grown on the untreated soils and that on soil receiving limestone applied beside the row in the inoculated series. The dry weight of the plants grown on the soil receiving limestone in the row was somewhat greater than that of the plants on the soils receiving limestone beside the row. The fully limed soils supported the greatest plant growth and the plants had the largest percentage nitrogen of all the plants grown.

The largest root growth was secured where limestone was applied in the row, however the dry weight of the roots of the plants grown on the fully limed soil was almost as great. The percentage nitrogen and total nitrogen content of the roots of the plants on the fully limed soils were larger than in the case of the plants on any of the other soils. The nitrogen content of the roots of the plants grown on the soils receiving limestone in the row approached that of the roots of the plants grown on fully limed soils.

The smallest crop with the lowest content of nitrogen was obtained on the untreated soils. The total dry weight and total nitrogen content of the plants grown on the soils receiving limestone beside the row were lower than in the case of the plants grown on soils receiving limestone applied in the row. The total dry weight and total nitrogen content of the plants grown on fully limed soil were greater than under any of the other treatments. In the case of the plants grown on the soils receiving limestone in the row, the yield and nitrogen content approached the figures for the plants grown on the fully limed soils. This was especially true for the total dry weight. The total dry weight and total nitrogen content of the plants were less where limestone was applied beside the row than when it was applied in the row.

NON-INOCULATED SERIES

The same general relationship between treatments and the dry weight and nitrogen content of the plants was observed in the case of the non-inoculated and inoculated plants; however, the differences were not as great in the non-inoculated series as in the inoculated series.

Comparing the non-inoculated series with the inoculated series, it is evident that the non-inoculated plants as a whole gave smaller crop yields and contained less nitrogen than the inoculated plants. These differences were highly significant.

SUMMARY AND CONCLUSIONS

An investigation was made on Shelby loam to study the effects of fine limestone applications in the row and beside the row on the yield and nitrogen content of inoculated and non-inoculated alfalfa plants. The plants were harvested at the stage of inflorescence, oven-dried, and analyzed for total nitrogen by the Kjeldahl method. The data obtained were analyzed statistically according to the method of analysis of variance and the results are summarized as follows:

1. A mercury dust used to control the "damping-off" organism probably prevented a thorough inoculation of the alfalfa grown in the inoculated series on Shelby loam.
2. In the inoculated series a concentration of nodules was observed in the limed zone where the fine limestone was applied in the row.
3. The total dry weight and total nitrogen content of the plants grown on fully limed soils were highly significantly greater than in the case of the plants grown on soils receiving limestone in the row or beside the row.
4. The total dry weight and total nitrogen content of alfalfa grown on the untreated soils was highly significantly less than those secured on the soils receiving limestone.
5. The nitrogen content of alfalfa grown on the variously limed soils varied similarly, irrespective of the degree of inoculation.
6. The total dry weight and total nitrogen content of alfalfa grown in the inoculated series on Shelby loam was highly significantly greater than those plants grown in the non-inoculated series.
7. The yield of alfalfa grown on the soil receiving 500 pounds of fine limestone in the row appeared to be nearly as great as that secured from the fully limed soil; however, the total nitrogen content of the plants was much less. Apparently the partial liming of Shelby loam is quite favorable for the growth of alfalfa but only as the full lime requirement of a soil is reached will maximum nitrogen fixation be obtained.

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THE STATISTICAL ANALYSIS OF A SPACING EXPERIMENT WITH SWEET CORN[1]

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DURING the past 15 years a variety of sweet corn, USDA-34, has been developed at the Puerto Rico Experiment Station of the U. S. Dept. of Agriculture, Mayaguez, Puerto Rico, and in a number of field trials has shown itself to be well adapted to the environmental conditions of the tropics.

Trial shipments of this variety of sweet corn have shown that good prices may be obtained when it is marketed in New York in the winter months. It was apparent, however, that there was a dearth of knowledge of the most efficient agronomic methods to use in the production of this sweet corn for market. Yields of nonmarketable ears and of forage also may be an important consideration for the grower operating a small enterprise typical of the Puerto Rican farm where a large return per acre per month is required to support the heavy population.

Accordingly, an experiment was designed to determine the relationship between soil area per plant and yield with USDA-34 sweet corn.

METHODS AND EXPERIMENTAL DESIGN

There were six spacing treatments in the experimental design. These varied by ½-square-foot intervals from 2.0 to 4.5 square feet per plant. The rows were spaced 2, 3, or 4 feet apart and the distance between hills was selected to give the required number of square feet per plant.

The field selected for the experiment was comparatively level and contained approximately 4 acres. The soil type has been classified as Catalina clay by the U. S. Bureau of Chemistry and Soils. Drainage was provided by parallel surface ditches across the field and they were necessary because of the high-intensity rainfall experienced during the months of the summer rainy season in which the corn was grown. To facilitate drainage, the land was plowed in such a way as to mound up the earth in the centers between the surface ditches. Plantings were made on ridges thrown up by the plow at right angles to the ditches and to a height of about 4 inches above the furrow.

In order to provide for statistical analysis of the data collected, a randomized block system of laying out the field was used. Each block contained one plat of each of the six spacing treatments. Twenty-five replications were used making a total of 150 plats or 3.84 acres in the experimental area. Plats measured 36×31 feet, each having an area of 1,116 square feet, or approximately 39 plats to the acre. The layout of the experiment as completed is shown in Fig. 1.

[1]Joint contribution from the Division of Biometry and Plant Physiology and Division of Agronomy, Puerto Rico Experiment Station, U. S. Dept. of Agriculture, Mayaguez, Puerto Rico. Received for publication September 20, 1937.

[2]Biometrician and Plant Physiologist and former Agronomist, respectively. The authors are indebted to Atherton Lee, Director of the Puerto Rico Experiment Station, who suggested and encouraged the investigation; to Wallace K. Bailey, Associate Plant Physiologist, Division of Vegetable Crops, who made the classifications of the ears; and to F. D. Richey, Chief of the Bureau of Plant Industry, for advice and comments.

Seeds were planted by hand May 18 to 23, 1936, at the rate of six per hill. Subsequently the hills were thinned to two plants at 10 days and one plant per hill at 3 weeks. Before planting, all seeds were poisoned against attacks of rodents and insects by soaking in a mixture of 1 pound of powdered arsenate of lead in 3 gallons of water for 5 minutes, followed by drying for 1 hour in the sun.

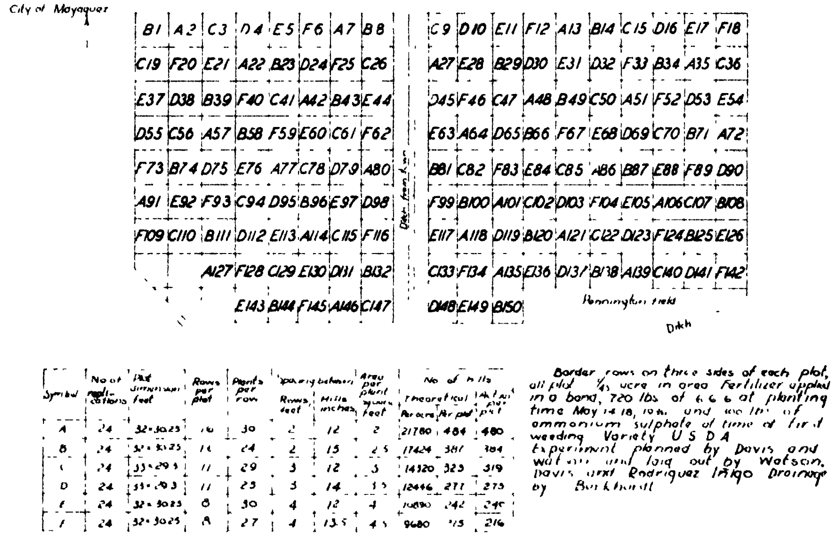

FIG. 1.—Spacing experiment with sweet corn at the Puerto Rico Experiment Station, U. S. Dept. of Agriculture, Mayaguez, P. R.

Fertilizer of a 6–6–6 formula was applied at the rate of 720 pounds per acre at the time of planting in a band to the side and about 1 inch below the level of the seed. This was followed by 300 pounds of ammonium sulfate 3 weeks after planting. Two cultivations were made with hoes for weed control, one at 3 weeks and the other at time of tasseling, 62 days from planting.

The experiment was harvested 92 days from planting on August 18 to 21, 1936. This was approximately 10 days after the marketable ears in some plats had reached the best edible stage of development. The ears were allowed to become air-dry in the greenhouse and subsequently were classified and weighed. This procedure was followed because rotting frequently is noticed in corn dried on the stalk during the rainy season in the region of Mayaguez. The forage was cut and weighed for each plat immediately after harvesting.

Classification of the ears of USDA-34, a recently bred variety, had previously been confined to a local standard of seed ears and culls. It was desired in the present investigation to classify yields on a basis comparable with yield data from trials at continental experiment stations. Standards were used that had been tentatively formulated by the Bureau of Agricultural Economics for classifying sweet corn intended for canning.

Counts taken at time of harvest showed that there had been considerable modification of the original allotted soil areas per plant because of stand differences. Table 1 shows a comparison of the soil area per plant at time of planting with the observed area per plant at time of harvest.

TABLE 1.—*Comparison of soil area per plant at time of planting and harvest in sweet corn-spacing experiment at Mayaguez, Puerto Rico.*

Treatment symbol	At time of planting			At time of harvest	
	Row distance, inches	Hill distance, inches	Soil area per plant, sq. feet	Stand, %	Average soil area per plant, sq. feet
A	24	12.0	2.0	71.7	2.79
B	24	15.0	2.5	75.8	3.30
C	36	12.0	3.0	88.1	3.41
D	36	14.0	3.5	88.5	3.95
E	48	12.0	4.0	76.3	5.24
F	48	13.5	4.5	75.7	5.94

It is shown in Table 1 that the percentage of stand varied among the various spacing treatments from 71.7 in treatment A to 88.5 in treatment C. These differences in stand among the various treatments must be considered in interpreting the results of an experiment.

RESULTS AND STATISTICAL ANALYSIS OF DATA

Table 2 presents the results of the experiment and Tables 3 and 4 the statistical analysis of the results.

TABLE 2.—*Comparative yields obtained with various soil areas per plant in sweet corn-spacing experiment at Mayaguez, Puerto Rico.*

Treatment symbol	Soil area per plant		Marketable ears per acre, number*	Average weight per marketable ear, ounces*	Shelled corn per acre, bushels†	Forage weight per acre at time of harvest, tons
	At time of seeding, sq. feet	At time of harvest, sq. feet				
A	2.0	2.79	2,272	3.827	32.5	3.096
B	2.5	3.30	2,027	3.893	29.0	2.735
C	3.0	3.41	2,269	4.144	32.4	2.944
D	3.5	3.95	1,857	4.066	26.5	2.486
E	4.0	5.24	1,411	4.061	20.2	1.801
F	4.5	5.94	1,347	4.068	19.2	1.883

*Marketable ears had at least 5 inches of grain, were well filled and formed, and showed no consequential insect damage.
†Shelled corn calculated from air-dry weights of all ears.

DISCUSSION OF RESULTS

The method of presentation of data and analysis used in Tables 2, 3, and 4 is believed to simplify the comparison of relative values of treatments in their effect upon the several items of yield.

This form of presentation also provides the reader with data for the critical examination of the experiment as a whole, as shown in Table 3. The significance of the effect of soil variation between blocks containing one plat of each treatment is readily observed in this table. The interaction variance of soil and treatment is used as a measure of error, and the degrees of freedom available for its estimate are included.

TABLE 3.—*Statistical significance of the experiment as a whole.*

Source of variance	Degrees of freedom	Variance* (averaged squared differences from the general mean plat of yields)			
		Marketable ears per acre, number*	Average weight per marketable ear, ounces*	Shelled corn per acre, bushels†	Forage weight per acre at time of harvest, tons
Between treatments	5	**	**	**	**
Between blocks.....	24	**	—	**	**
Interaction (error)..	120	578	.0002418	.008218	.0002239

*Marketable ears had at least 5 inches of grain, were well filled and formed, and showed no consequential insect damage.
†Shelled corn calculated from air-dry weights of all ears.
*Dash (—), single star (*), and double stars (**) indicate nonsignificance (odds of 20 to 1 or less), significance (odds of less than 100 to 1 and greater than 20 to 1), and high significance (odds greater than 100 to 1), respectively.

TABLE 4.—*Statistical significance of difference between treatments.*

Treatment difference symbols	Comparison of soil areas per plant at time of harvest, sq. feet	Significance of the differences*			
		Marketable ears per acre, number*	Average weight per marketable ear, ounces*	Shelled corn per acre, bushels†	Forage weight per acre at time of harvest, tons
A vs. B	2.79 vs. 3.30	**	—	**	*
A vs. C	2.79 vs. 3.41	—	**	—	—
A vs. D	2.79 vs. 3.95	**	**	**	**
A vs. E	2.79 vs. 5.24	**	**	**	**
A vs. F	2.79 vs. 5.94	**	**	**	**
B vs. C	3.30 vs. 3.41	**	**	**	—
B vs. D	3.30 vs. 3.95	—	*	*	—
B vs. E	3.30 vs. 5.29	**	*	**	**
B vs. F	3.30 vs. 5.95	**	*	**	**
C vs. D	3.41 vs. 3.95	**	—	**	**
C vs. E	3.41 vs. 5.24	**	—	**	**
C vs. F	3.41 vs. 5.95	**	—	**	**
D vs. E	3.95 vs. 5.24	**	—	**	**
D vs. F	3.95 vs. 5.94	**	—	**	**
E vs. F	5.24 vs. 5.94	—	—	—	—

*Marketable ears had at least 5 inches of grain, were well filled and formed, and showed no consequential insect damage.
†Shelled corn calculated from air-dry weights of all ears.
*Dash (—), single star (*), and double stars (**) indicate nonsignificance (odds of 20 to 1 or less), significance (odds of less than 100 to 1 and greater than 20 to 1), and high significance (odds greater than 100 to 1), respectively.

It should be noted that Table 3 was computed from the figures on yields per plat and the variance shown for each yield item is on that basis. The figures in Table 2 presented on the basis of yields per acre in no way change the comparisons of treatments made in Table 4 on the plat basis.

Table 4 is devoted to a comparison of all combinations of pairs of treatments for each item of yield, based upon the respective error variances.

When used in conjunction with Figs. 2 and 3, which portray graphically the results shown in Table 2, the latter table provides a quick and accurate method of appraising the value of any treatment. An example of the ease with which they may be accomplished may be cited. In Fig. 2 it is noted that the total number of marketable ears as

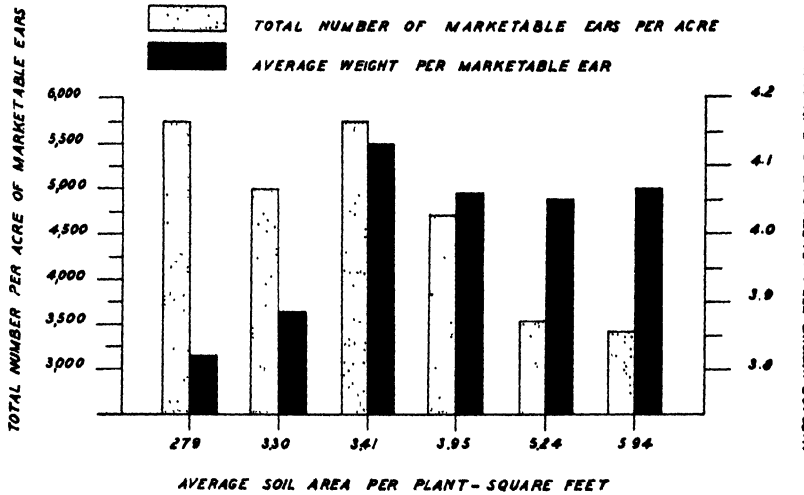

FIG. 2.—Number and average weight per ear of marketable ears produced with various soil areas per plant.

represented by the height of the dotted bar at 3.30 square feet per plant was slightly greater than the number produced with the spacing of 3.95 square feet. Reference to Table 4 under the column heading "number of marketable ears per acre", shows that when 3.30 square feet are compared with 3.95 square feet the difference in numbers of marketable ears produced was not significant as indicated by

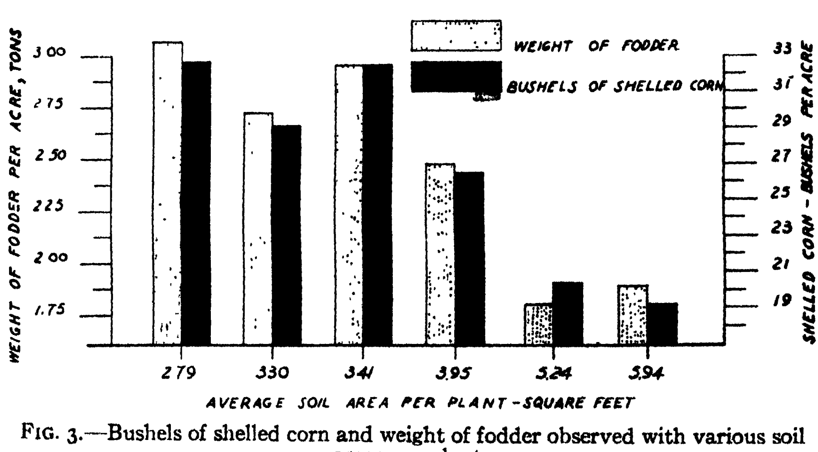

FIG. 3.—Bushels of shelled corn and weight of fodder observed with various soil areas per plant.

the dash (—). Other comparisons suggested by inspection of the chart may be made as readily.

It is apparent in Fig. 3 that there was a marked decrease in production of both fodder and shelled corn when soil areas per plant were greater than 3.41 square feet. The same tendency is noted in Fig. 2 as regards numbers of marketable ears.

The average weight per marketable ear was adversely affected by the smaller areas per plant, although the number of marketable ears was not significantly reduced by the closer spacing. In this experiment the critical area per plant for average weight of marketable ears appeared to lie between 3.30 and 3.41 square feet. When the spacing per plant was increased beyond 3.41 square feet, there was no significant increase in ear weight, and with lessened space per plant the weight was decreased significantly. This is shown graphically in Fig. 2.

The plats for both the 2- and 4-foot-row spacings were plowed into ridges every 2 feet and the 4-foot spacing was obtained by planting on every other ridge. The tillage operations to obtain the spacing of 3 feet between rows resulted in ridges about 9 inches in width at the base. This was approximately 50% wider than the ridges for the 2- and 4-foot-row spacings, which were about 6 inches wide at the base.

The tops of all ridges were leveled by a potato hiller, which resulted in a width of about 2 inches at the top of the ridge of 2- and 4-foot spacings and in a width of about 4 inches in the 3-foot-row spacing. This procedure was justified from the point of view that the difference in width of planting ridge was a part of the treatment difference. However, differences in anchorage were accentuated by a high wind which passed over the field at the time of silking and caused more lodging in the 2- and 4-foot spacings than on the wider ridges of 3-foot spacings. Opportunity was therefore taken to determine comparative lodging in the different treatments and also the effect of the different spacings on average diameter of the corn stalks. These data are presented in Table 5.

TABLE 5.—*Differences in lodging and diameter of stalks observed with various soil areas per corn plant.**

Treatment symbol	Average soil area per plant at time of planting, square feet	Lodging, %	Average diameter of lowest internode of stalk, cm†
A	2.0	16.7	1.95
B	2.5	18.0	2.01
C	3.0	11.6	2.13
D	3.5	8.2	2.18
E	4.0	15.0	2.18
F	4.5	14.6	2.16

*These data were recorded by Mr Jorge Rodríguez Iñigo, under scientific aid.
†Based on counts of 10 stalks in each of 20 plats of each treatment.

The data in the last column of Table 5 indicate that a difference of approximately 10% in average diameter of stalks existed between the closest spacing of treatment A and the widest spacing of treatment F. Data were not available for testing the statistical significance of the results shown in Table 5.

This table also shows that better stands and less lodging occurred in treatments C and D which, because of the cultivation requirements of the different spacing treatments, had the widest planting ridges. The lower percentages of lodging of treatments C and D apparently resulted from greater width of planting ridge. Measurements showed practically no difference in stalk diameter between the corn of these treatments and that of treatments E and F.

It has already been shown in Table 1 that modification of the original spacings was caused by differences between the stand at time of planting and stand at time of harvesting. In the case of a 75% stand resulting in approximately the same average area per plant at time of harvest as another spacing treatment with 90% stand, the latter treatment might be expected to have higher yields per plant because of better land utilization by the individual plants. It is believed that such a factor was operating in this experiment, resulting in superior yields of treatment C over treatment B.

It is interesting to note that series E and F gave almost the same results for all items of yield. Apparently the treatment having the larger area per plant yielded enough more per plant to compensate for the smaller number of plants per acre it contained.

In treatments C and D, with practically equal stands, competition was becoming more severe with less soil area per plant, but for all yield items, except average weight of marketable ear, the closer of the two spacings, or 3.41 square feet per plant, yielded better.

A comparison between treatments A and B cannot be made so logically because of differences in percentage stand. The closer spacing continued to increase numbers of marketable ears, weight of shelled corn, and forage weights. Moreover, the decrease of weight of marketable ear was not statistically significant. However, the sharp drop noted in this weight when soil areas per plant decreased below 3.41 square feet would probably eliminate the closer spacing from consideration for growing the USDA-34 variety of sweet corn at this station.

Because of numerous biological factors which enter in to reduce stands in corn experiments in the vicinity of Mayaguez, the practice is now being followed of planting rows 3 feet and hills 1 foot apart with final thinning to one plant per hill. Three square feet per plant at time of planting then increases to approximately 3.4 square feet with usual reductions in stand.

The large number of replications used was based on the principle that the smaller the experimental differences expected, the greater must be the number of replications. With the large numbers of replications in this experiment, it is felt that in the case of yield differences which were nonsignificant, the spacing practice to be followed would depend on economy rather than on yields.

SUMMARY AND CONCLUSIONS

1. An experiment in spacing, using six different soil areas per plant, was conducted with the USDA-34 variety of sweet corn to determine the effect of spacing on numbers and weight of marketable ears, yields of shelled corn, and forage weights. Plantings were made on

ridges with one plant per hill. Variation in soil area per plant was accomplished by varying both the row and hill planting distances. The experiment, which contained 25 replications of the plats of each treatment, was designed to provide for statistical analysis of the results.

2. The closest spacing used, or 2.79 square feet of soil area per plant at time of harvest, gave the highest yield of shelled corn and fodder.

3. Increasing numbers of marketable ears were noted as the soil area per plant became smaller, but this was attended by a significant decrease in average weight per marketable ear when the area was less than 3.41 square feet per plant.

4. Planting ridges 4 inches wide at the top and 9 inches wide at the base showed less lodged corn after a high wind than ridges which measured 2 inches at the top and 6 inches at the bottom.

5. Diameter of lowest internode of corn stalks increased with increase of the soil areas up to 3.95 square feet per plant. Further increases in area per hill did not result in increased diameters of the stalks.

NUT GRASS ERADICATION STUDIES: II. THE ERADICATION OF NUT GRASS, *CYPERUS ROTUNDUS* L., BY CERTAIN TILLAGE TREATMENTS[1]

E. V. Smith and E. L. Mayton[2]

IN an effort to eradicate any troublesome weed, the best procedure would seem to be to study fully the life history of the pest in the hope of finding periods in its life cycle at which it is most susceptible to attack. Accordingly, the eradication studies on the nut grass plant, *Cyperus rotundus* L., reported in this and later papers, represent an outgrowth of the life history studies reported by Smith and Fick.[3] Their results showed that nut grass reproduces itself principally, if not solely, by tubers and basal bulbs. It was shown also that this plant forms a rather complex system of aerial and underground parts all of which act as a physiological unit. The tubers and basal bulbs which represent a part of the underground system do not all germinate unless each tuber or basal bulb is separated from the rest of the system. Data are also given showing that exposure of these parts to drying was very effective in reducing their viability.

Consequently, it seemed reasonable that the following of a systematic schedule of tillage treatments on nut grass-infested land might be effective in eradicating this pest. Such treatments would tend to break apart the plant systems and expose many of the isolated tubers and basal bulbs to drying at or near the surface of the soil. Other tubers in more moist soil would be stimulated to germinate as a result of isolation. Smith and Fick[4] also presented data which showed that in a sandy soil less than 1% of the viable tubers was below the possible plow depth. This fact is of particular advantage in tillage treatments.

EXPERIMENTAL

In order to study the effects of tillage treatments on nut grass a series of nine plats, each 20 by 110 feet, was laid out in a rather heavily infested area of Norfolk sandy loam soil in 1934. The original infestation of each plat was determined by screening out the tubers in the surface soil (approximately 8 inches) of three definitely located areas, each 2 by 2 feet. In preliminary work it was found that this method was the best to use in determining the infestation of an area. A count of aerial shoots is unreliable because of a much greater potential infestation represented in dormant underground tubers. The live tubers were determined by paring off small slices with a knife or slitting them with the thumb nail and noting the color. In laboratory work with tubers it had been found that only the firm, crisp tubers showing little or no discoloration on the inside were capable of germinating.

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[2]Associate Botanist and Assistant Agronomist, respectively.

[3]Smith, E. V., and Fick, George L. Nut grass eradication studies: I. Relation of the life history of nut grass, *Cyperus rotundus* L., to possible methods of control. Jour. Amer. Soc. Agron., 29:1007–1013. 1937.

[4]*Loc. cit.*

The infestation records were taken early in June, 1934, and the tillage treatments were begun on June 9 and extended throughout October. The various plats were either plowed or disked at regular intervals with one plat being left untilled as a control. The plow used was of the moldboard type which leans the furrow slice against a previous one instead of completely inverting it. The disk harrow used was the two-horse type equipped with ten discs approximately 16 inches in diameter. In the disking operation the plats were "double-cut" at each disking.

Separate plats were plowed or disked at 1-, 2-, and 4-week intervals throughout the season. One plat was plowed and another was disked when sprouts were general over the area. The interval between tillage treatments on the plats throughout 1934 was approximately 3 weeks. The same treatments were begun on April 24, 1935, and again extended throughout October. The plowing and disking operations were done as nearly on schedule as weather conditions would permit and in no instance did they vary from the specific date more than three days.

Infestation records were again taken on three definitely located 2 by 2 foot areas (each adjacent to a previously dug area) at the end of the 1934 season and at the beginning and end of the 1935 season. These data are presented in Table 1.

TABLE 1.—*The effect of tillage treatments on the infestation of nut grass.*

Plat No.	Treatment	Number of live tubers*		Percentage reduction during 1st season	Number of live tubers*		Percentage reduction over two seasons
		Beginning of experiment June 1, 1934	End of 1st season Nov. 17, 1934		Beginning of 2nd season April 13, 1935	End of 2nd season Dec. 14, 1935	
1	Plowed every week	80	15	81	15	0	100
2	Plowed every 2 weeks	87	14	84	17	0	100
3	Plowed every 4 weeks	66	119	+80	66	1	98
4	Plowed whenever sprouts were general over area	71	14	80	13	4	94
5	No treatment	46	145	+220	146	191	+315
6	Disked every week	41	10	76	6	0	100
7	Disked every 2 weeks	67	14	79	15	0	100
8	Disked every 4 weeks	44	45	+2	18	13	70
9	Disked whenever sprouts were general over area	67	14	79	7	0	100

*Each figure is the average of three 2 by 2 foot diggings.

RESULTS

The data in Table 1 show that nut grass was either completely eradicated or very nearly eradicated on all treated plats except the one disked every 4 weeks. On the plats plowed or disked every week, every second week, or whenever sprouts were general over the area, the infestation was reduced approximately 80% during the first season. An increase in infestation during 1934 is shown where tillage operations were at 4-week intervals, but the infestation records in the spring of 1935 indicate a rather high mortality during the winter.

Since a new tuber is formed in approximately 3 weeks, the majority of the live tubers from the fall diggings of 1934 on plats 3 and 8 were very small. Such newly formed tubers contain a very low food reserve and a high mortality was to be expected. There was a steady increase in infestation throughout the two years on the control plat.

The indication of eradication by the tillage treatments was so striking that it was thought advisable to check the results shown in Table 1 by determining the infestation on a larger area of each plat. Accordingly, in March, 1936, the surface soil from the center one-fourth of each plat was screened and the number of live and dead tubers determined. These results are presented in Table 2. With the exception of the tubers from the control plat, all tubers which were apparently alive were brought into the laboratory and placed in a germinator; thus the number of live tubers shown in Table 2 is the number which actually produced new plants. These data show that nut grass was completely eradicated by plowing treatments at intervals of 3 weeks or less over two consecutive growing seasons. The disking treatments were almost as effective.

TABLE 2.—*Final tuber infestation following tillage treatments for two successive growing seasons.*

Plat No.	Treatment	Tuber infestation, March 1936*	
		No. of live tubers	No. of dead tubers
1	Plowed every week	0	Not determined
2	Plowed every 2 weeks	0	2,490
3	Plowed every 4 weeks	13	5,202
4	Plowed whenever sprouts were general over plat	0	1,940
5	No treatment	17,377	9,559
6	Disked every week	1 (sprout very weak)	1,838
7	Disked every 2 weeks	0	3,093
8	Disked every 4 weeks	67	3,794
9	Disked whenever sprouts were general over plat	5	754

*Areas dug were 10 by 55 feet.

All plats were left undisturbed during the 1936 season to see if any nut grass came back on the different plats. At each end of each plat an area 10 by 13¾ feet was staked for regular observations during this season as a final check on the efficiency of the plowing and disking treatments. Observations were made at 2-week intervals beginning June 18 and ending September 1. No plants occurred on plats which had been plowed at 1- or approximately 3-week intervals. A total of eight plants developed on the plat plowed at 4-week intervals and one plant on the plat plowed every 2 weeks. This plant was carefully dug and found to arise from a tuber 12 inches below the soil surface. This tuber had apparently lain dormant in the soil for 2½ years. No plants were found on the plats disked at intervals of 1, 2, or approximately 3 weeks. On the plat disked every 4 weeks, a total of 150 plants was found on the two small areas. At the end of the season this plat carried a generally light infestation over its whole area.

DISCUSSION

The results of this experiment indicate that it is possible to eradicate nut grass on sandy soils by either plowing or disking at intervals of 3 weeks or less throughout two successive growing seasons. Such treatments would of course prevent the growing of a summer crop on the land, but a winter grain or hay crop which is planted in October and harvested by the first of June might be grown. Such a crop, in fact, would be desirable because land fallowed throughout the summer is very susceptible to erosion losses in the winter and a winter crop would give considerable protection. Nut grass will make very little growth in a dense crop of grain or winter legumes and tillage treatments would not be seriously delayed by such crops.

Intensive tillage treatments may not be feasible on a whole farm infested with nut grass, but they are very practical when small areas occur in fields. Such areas serve to infest the whole field in the course of a few years. A considerable amount of labor and time may be very wisely spent on the eradication of nut grass from small areas before it spreads to larger areas. The use of tillage treatments here described offers a means for complete eradication of nut grass on light sandy soils.

SUMMARY

Studies on the eradication of nut grass by tillage treatments are presented. It was found that plowing or disking at intervals of 3 weeks or less during two consecutive growing seasons completely eradicated nut grass on a Norfolk sandy loam soil. Such treatments reduced the infestation approximately 80% the first year.

THE VALUE OF COVER CROPS IN CONTINUOUS CORN CULTURE[1]

T. E. ODLAND AND H. C. KNOBLAUCH[2]

THE use of cover crops for the purpose of conserving soil fertility, whenever possible, is becoming a general practice on the better managed farms in Rhode Island as well as in many other localities. Specific evidence on the value of such practice over a considerable period of time is, however, not so plentiful. Results obtained with nonlegume cover crops have sometimes been contradictory. The purpose of this paper is to present some results from a long-continued experiment with rye and clover cover crops in continuous corn culture at the Rhode Island Agricultural Experiment Station.

Pieters[3] has reviewed the literature on green manuring for various crops and with the use of different green manure and cover crops. Generally, very beneficial results have been obtained from legume green manure crops. Nonlegume crops, especially rye, have not always been of benefit to certain succeeding crops. In several instances the results reported showed a detrimental effect of a rye cover or green manure crop on a succeeding crop of corn.

More recently, Sprague[4] has reported results obtained with seven different green manure crops used with continuous corn over a 5-year period. The legume green manure crops used showed beneficial effects on the succeeding corn crops, but no increase in yield over the check plat was obtained from the use of wheat or rye.

DESCRIPTION OF EXPERIMENT

The experiment in continuous corn culture was begun in 1894. The purpose, as stated in an early bulletin from the Rhode Island Station, was to determine the "feasibility of attempting to grow corn or other plants continuously upon the same land without the introduction of intermediate crops or the use of farm manures, the sole dependence for the maintenance of fertility to be placed upon commercial fertilizers". This experiment was continued until 1933 under this plan. The area included consisted of 1 acre of land. The soil is classified as Bridgehampton very fine sandy loam, is underlain by gravel, and is well drained.

In 1898 this acre was divided into four equal parts for the purpose of comparing legume and nonlegume cover crops with no cover crop. Two sections, 2 and 4, were left without cover crops; one section, 3, had rye sown in the corn at the last cultivation and another section, 1, had a legume cover crop seeded at the same time.

In 1915 the test was modified in that the amount of nitrogen applied in the fertilizer was considerably increased on all sections except the one seeded annually to a legume cover crop.

In 1922 another change was made in that on section 4 the ears were husked from the standing corn and the stalks later plowed under. For three years previous to

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[2]Agronomist and former Assistant Agronomist, respectively.

[3]PIETERS, A. J. Green Manuring. New York: John Wiley & Sons Inc. 1927.

[4]SPRAGUE, H. B. The value of winter green manure crops. N. J. Agr. Exp. Sta. Bul. 609. 1936.

this, straw had also been applied to this section. A more detailed description of the test with results obtained to 1918 may be found in Bulletins 113 and 173 of the Rhode Island Experiment Station.

In this paper the results obtained during the years 1900 to 1933, inclusive, will be considered. The crop for 1899 is omitted since this was the first year after the change to the plan of using no cover crops on two sections.

The fertilizer applied has varied considerably. The average application for the period of 1900 to 1933 was approximately 1,200 pounds per acre of a 5–8–7 fertilizer on sections 2, 3, and 4. Since 1915 only about one-third to one-half as much nitrogen was applied to section 1 receiving the legume cover crop. In 1926 section 3 was again divided into north and south halves and an increased amount of nitrogen applied in the fertilizer on the north half. The yield figures for the different sections presented in this paper are based on the south half only of this section for the years since that time. This half continued to receive the same amount and kind of fertilizer as sections 2 and 4.

The amount of fertilizer used is somewhat more than is ordinarily applied for corn where this is grown in a rotation with other crops. The heavy application was used in order to eliminate the factor of insufficient soil nutrients as far as possible.

Lime has been applied at four different times during the course of the experiment. The total amount has been the equivalent of about 6 tons of ground limestone per acre. In addition, a total of nearly 3 tons per acre of wood ashes were used over the period 1918 to 1921 to supply potash. This would be the equivalent of approximately 2 tons of limestone in its effect on soil acidity. Basic slag was used frequently during the early years of the experiment as the source of phosphoric acid. The total amount used carried an equivalent of approximately 1½ tons per acre of limestone. During the course of the experiment, therefore, a total of soil acidity correctives to the extent of about 9½ tons of limestone per acre have been added. This has resulted in maintaining a pH of about 6.5 over the greater part of the time. Section 1 has been inclined to show the greatest amount of soil acidity whenever tests have been made. The differences have been small, however, among the four sections.

The soil on which this experiment was located is fairly uniform, although it is somewhat deeper and heavier on section 1 which is on the east side. Westward through sections 2, 3, and 4 the soil becomes a little more shallow and lighter. Although these differences are not great they should be kept in mind when considering the results obtained.

The legume cover crops have consisted of different clovers, either alone or in mixtures with winter vetch or winter vetch and alfalfa. A mixture of red, alsike, and sweet clover was the predominant cover crop during the last 10 years of the test. During the first 24 years, crimson clover was usually used either alone or in mixtures with winter vetch and other clovers. The cover crops have generally been seeded in the corn during the first week in August and plowed under the middle of the following May.

The growth of the legume cover crop was not very satisfactory some years, while in others a good cover was obtained. Winter injury to the cover crops varied with the seasons and with the crop used. A mixture of red, alsike, and sweet clover was the one finally adopted as the most reliable under local conditions.

The winter rye used each year as a cover crop on section 3 has usually been seeded at the rate of 70 pounds per acre at the last cultivation of corn. The growth obtained before plowing under has varied from a few inches in height to as high as 2 feet.

At harvest time the corn was husked, weighed, and acre yields of shelled corn computed. The ears were separated into hard and soft corn on the basis of maturity.

In 1934, this test was discontinued in order to make the space available for other experimental work. Enough soil was taken from each section, however, to fill a "cement frame" approximately 5 feet by 10 feet in size to a depth of 8 inches. The original plan of cover crops and fallowing is being continued in these frames.

YIELD OF GRAIN

The yields obtained for the years 1915 to 1933, inclusive, are presented in Table 1. The average yield for the periods of 1900 to 1905 and 1906 to 1914, as published previously, are also shown.

TABLE 1.—*Yields of corn grown continuously with and without cover crops at the Rhode Island Agricultural Experiment Station, Kingston, R. I., in bushels per acre.**

	Hard corn				Soft corn				Stover			
	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4
Ave. 1900–1905†	43	31	35	29	5	5	5	6	1.9	1.5	1.8	1.7
Ave. 1906–1914†	43	25	28	16	6	5	4	4	1.8	1.4	1.6	1.3
1915	56	38	42	28	7	6	7	8	3.0	2.1	2.8	2.0
1916	19	7	14	4	5	3	7	8	1.3	1.2	1.5	1.3
1917	41	28	33	18	10	12	13	12	2.1	1.2	1.2	1.2
1918	54	47	53	45	4	3	3	5	1.7	1.5	1.7	1.9
1919	40	32	43	42	4	6	5	5	1.8	1.9	2.3	2.4
1920	48	28	35	26	4	4	5	5	2.1	2.0	2.2	2.1
1921	81	52	68	51	3	3	2	3	3.1	2.3	2.3	2.4
1922	44	36	38	29	3	2	4	6	2.2	2.4	2.4	—
1923	31	33	35	39	7	4	5	4	1.5	1.5	1.6	—
1924	18	15	15	16	6	7	7	8	2.2	1.8	2.2	—
1925	39	53	53	63	2	2	1	2	2.6	2.8	3.0	—
1926	48	57	70	65	4	3	4	4	4.0	3.7	4.1	—
1927	31	33	36	31	2	1	1	2	3.0	2.9	3.0	—
1928	54	43	52	46	4	3	3	4	4.2	3.7	5.0	—
1929	54	57	67	67	1	1	1	4	2.2	2.3	3.2	—
1930	20	21	31	26	5	5	6	6	2.7	2.8	3.6	—
1931	33	39	48	36	5	5	8	5	1.9	2.2	2.4	—
1932	67	32	36	35	3	3	3	2	3.0	2.3	3.0	—
1933	33	36	52	35	—	—	—	—	2.8	2.9	3.2	—
Ave. 1915–1933	43	36	43	37	4	4	4	5	2.5	2.3	2.7	—
Ave. 1900–1933	43	32	38	30	5	4	4	5	2.2	1.9	2.2	—

*Section 1 = Legume cover crop; Section 2 = No cover crop; Section 3 = Rye cover crop; and Section 4 = No cover crop (corn stover plowed in beginning in 1922).

†See R. I. Agr. Exp. Sta. Bul. 173.

The average total yields of shelled corn, hard and soft, for the first 6-year period, 1900 to 1905, were 48, 36, 40, and 35 bushels per acre, respectively, following the legume cover crop, fallow, rye, and fallow. If the two adjoining sections, 1 and 2, are compared, it will be seen that an increase of 12 bushels per acre was obtained by the use of the legume cover crop. An increase of 4 bushels per acre was obtained from the rye cover crop when this is compared with the same check or fallow section.

For the 9-year period of 1906 to 1914, the average yields on the same sections were 49, 30, 32, and 20 bushels, respectively. Here again the legume cover crop produced a very sizable increase in yield over the adjoining fallow sections. The average increase in yield obtained on the rye cover crop section was only 2 bushels over that on fallow section No. 2, but 12 bushels over that on section 4 which was also one without a cover crop. Although the soil becomes gradually somewhat lighter from section 1 to 4, this does not seem a sufficient reason for the low yield on section 4 over this period. The cause of this low average yield is not evident.

The average annual yields of shelled corn for the 19-year period of 1915 to 1933 were 47, 40, 47, and 42 bushels per acre on sections 1, 2, 3, and 4, respectively. During this period the first section where the legume cover crop was used received only one-third to one-half as much nitrogen in the fertilizer as was applied to the other sections. Since the plan of plowing under the stover on section 4 was introduced during this period, the yields on this section cannot be used for a strict comparison with the other uniformly treated sections.

Despite the fact that the nitrogen applied to section 1 was considerably reduced, the yields were maintained so that the average on this section was the same as on section 3 with the rye cover crop and considerably heavier nitrogen fertilization. These two sections outyielded the fallow section, No. 2, by an average of 7 bushels of shelled corn per acre. In both cases the odds[5] show this to be a significant increase in yield over the no cover crop section.

When the yields over the entire 34-year period, 1900–1933, are compared, the average yields are 48, 36, 42, and 35 bushels of shelled corn per acre for sections 1, 2, 3, and 4, respectively. Only section 2 with no cover crop and section 3 with a rye cover crop can be strictly compared over this period. The south half of section 3 was used for the comparison since 1926. The sections have received the same amount of fertilizer and were otherwise treated alike over the entire period with the exception of the rye cover crop. Section 1 is not strictly comparable due to the change made in nitrogen applied in the fertilizer and section 4 has been partly left fallow and partly had the corn stalks plowed in.

Over the entire 34-year period the average increase in yield of section 3 with the rye cover crop over that of section 2 without a cover crop has been 6 bushels of shelled corn per acre. When the odds are calculated, it is found that the chances are over 10,000 to 1 that this is a significant increase in yield. This increase in yield can definitely be accepted as being due to benefits derived from the cover crop since several uniform crops of corn previous to the beginning of the experiment had shown that the soil where sections 1 and 2 are located was a little higher in yielding capacity than the soil where sections 3 and 4 are located. Examination of the soil profile also shows section 2 to have a little deeper and heavier topsoil than section 3. The higher

[5]Odds less than 30 to 1 not considered significant. Odds calculated according to Student's method as reported by Love, H. H., in "A modification of Student's table for use in interpreting experimental results". Jour. Amer. Soc. Agron., 16: 68–73. 1924.

yields on section 1, however, should perhaps be discounted a little due to its being a slightly heavier soil type than that of section 2. The variation in the original fertility of soil, however, was not large and ordinarily it would be considered very uniform in this respect.

The cause of detrimental effects noted on crops from a previous nonlegume cover or green manure crop has often been ascribed to a competition of the decaying vegetable matter and the growing crop for the available soil nitrogen. Addition of more nitrogen in the fertilizer to supply enough both for the decaying vegetable matter and the growing crop has been suggested as the remedy. Examination of the data where adverse results from rye and other nonlegume green manure crops have been reported often shows that failure to provide sufficient nitrogen in the fertilizer could easily be an explanation of the results obtained.

Although what was considered to be a very liberal application of nitrogen was applied to the corn crops in this experiment from its beginning, it was decided in 1926 to add even more on one-half of the rye cover crop section. This section was therefore divided and 25% more nitrogen applied to the north half than was applied on the other half and on the fallow section. In 1927 and subsequent years 50% extra was applied instead of 25%. The yields on the two halves are shown in Table 2.

TABLE 2.—*Total yields of corn on section 3, 1926 to 1933, in bushels per acre.*

Year	North half, extra nitrogen	South half, regular nitrogen
1926	77	74
1927	50	37
1928	64	55
1929	95	68
1930	55	37
1931	74	56
1932	55	39
1933	59	52
Average	66	52

The yields obtained show that a material increase resulted nearly every year. The average annual increase in yield for the extra nitrogen was 14 bushels per acre. This extra yield was obtained from an additional 30 pounds of nitrogen applied annually in the fertilizer. These results indicate that even a greater benefit would have been shown by the rye cover crop if a fertilizer higher in nitrogen had been used throughout the test. Other experiments at this station have repeatedly shown that crops respond best, in general, to generous fertilizer applications when the soil is well supplied with organic matter. The additional 14 bushels of shelled corn was a well worthwhile return on the additional nitrogen applied in the fertilizer.

YIELD OF STOVER

The yields of stover have varied considerably from year to year on this experiment. In general, the yields of stover have been in the

order of the yields of grain on the corresponding sections. For the entire 34-year period, the average yield on section 1 with the legume cover crop was 2.2 tons of field dried stover per acre (Table 1). The same average was produced on section 3 with a rye cover crop but with more nitrogen applied in the fertilizer. The average yield on the fallow section, No. 2, was 1.9 tons per acre. The rye cover crop apparently was effective in producing an increased yield of stover as well as grain when compared with the fallow section.

EFFECTS OF COVER CROPS ON THE SOIL

NITROGEN CONTENT

Total nitrogen determinations have been made on the soil from the different sections of this experiment at various times.[6] One of the benefits that presumably should be derived from the use of cover crops is the maintenance of the soil organic matter which in turn should be reflected in the total nitrogen content of the soil. The nitrogen determinations made in 1914 and 1933 are shown for comparison in Table 3. No determinations previous to 1914 are available.

TABLE 3.—*Total nitrogen in soil of continuous corn experiment.*

Section No.	Percentage N		Pounds N per acre	
	1914	1932	1914	1932
1	0.1947	0.1763	3,894	3,526
2	0.1326	0.1180	2,652	2,360
3	0.1353	0.1332	2,706	2,664
4	0.1160	0.1199	2,320	2,398

The results of the nitrogen determinations show that in 1932, after 40 years of continuous cropping to corn, the total nitrogen where no cover crop was used had been reduced to a very low level. The total nitrogen content on this section had been reduced to 0.1180%. Soil of this type in adjoining plats where crop rotation and adequate fertilization is practiced will average about 0.20% total nitrogen. The total nitrogen content on section 1 had been reduced from 0.1947% in 1914 to 0.1763% in 1932. Section 2 without a cover crop was reduced from 0.1326 to 0.1180%, while on the rye cover crop section, No. 3, the reduction was only from 0.1353 to 0.1332%. Section 4 was very low at both sampling dates, but showed a small gain. This could be accounted for on the basis of the plowing under of the stover during the last 12 years of the test. Both the legume cover crops and rye alone have helped in preventing the total nitrogen content from becoming depleted as rapidly as where no cover crop was used.

When the percentages are translated into pounds of nitrogen per acre as shown in the table, the range is from 2,320 to 3,894 pounds per acre in 1914 and from 2,360 to 3,526 pounds in 1932. This again brings out the fact that the rye cover crop has decidedly reduced the

[6]The authors are indebted to John B. Smith for nitrogen and moisture determinations. The Kjeldahl-Gunning-Arnold method for total nitrogen was used.

rate of loss of organic matter from the soil as measured by total nitrogen content and compared with the fallow section.

MOISTURE

Soil organic matter is of benefit to crops in adding to the water-holding capacity of the soil. If green manuring and the growing of cover crops help to conserve the organic matter of the soil they should also help to maintain a better water-holding capacity.

In this experiment it has been generally observed that the sections with cover crops have apparently suffered less from dry spells than those without cover crops. In order to check on the actual moisture-holding capacities of these different sections, moisture determinations were made at various times. Section 2 with no cover crop and section 3 with the rye cover crop were generally used for making these determinations. In the years 1926, 1927, and 1928 a series of soil moisture determinations were made on these two plats over a period of several months each summer. The results are shown in Table 4.

TABLE 4.—*Soil moisture determinations on sections 2 and 3 during the seasons of 1926 to 1928, inclusive.*

Year	Number of determinations	Period covered	Average percentage of moisture	
			Section 2, fallow	Section 3, rye cover crop
1926	4	June–Aug.	19.0	22.1
1927	10	Apr.–Aug.	23.8	27.4
1928	7	June–Aug.	23.9	28.1

As may be seen from these figures, the rye cover crop on section 3 had increased the water-holding capacity so that on an average the soil contained from 3 to 4% more water than on the fallow section. When the moisture content of the soil is at a critical point for the crop this additional water-holding capacity may mean considerable in the final yield.

SUMMARY AND CONCLUSIONS

Corn was grown continuously over a period of 40 years with a comparison of both legume and nonlegume cover crops and no cover crop. Variations in fertilization and disposition of the corn stover were also included.

The legume cover crops were the most effective in maintaining the yields of corn in this test.

Winter rye seeded at the last cultivation of the corn in the fall increased the average annual yield by 6 bushels per acre over the adjoining no-cover-crop section for the 34 year period of 1900–1933.

The yields of stover were increased by both the legume and rye cover crops. The increase in yield of stover was not as large in proportion, however, as the increase in yield of grain.

Increasing the nitrogen content in the fertilizer by 50% on one-half of the rye cover crop section resulted in an average annual increase

of 12 bushels per acre over the half with the regular amount of nitrogen.

The total amount of nitrogen in the soil showed a gradual decrease on all sections. Both the legume and rye cover crops lessened the rate of decrease in total nitrogen.

The cover crops used increased the water-holding capacity of the soil.

This experiment has definitely shown that under conditions such as prevail where this test was conducted the practice of using cover crops for conserving soil productivity is a highly desirable practice and should be encouraged. Where a legume cover crop can be used successfully this is to be preferred. Rye, although a nonlegume, will also show decided benefits to the soil and crop grown.

CHANGES IN COMPOSITION OF GRANULAR AND POWDERED FERTILIZERS IN THE SOIL[1]

CHARLES B. SAYRE AND ARTHUR W. CLARK[2]

RECENTLY there has been a marked increase in the use of granulated fertilizers accompanied by an increasing interest in the physical and chemical properties of the granulated forms as compared with ordinary powdered forms of fertilizers. Consequently, some studies were undertaken at the New York State Experiment Station at Geneva to determine the relative rates of solution and the changes that take place in granulated and powdered fertilizers after they have been applied to the soil.

In a previous publication,[3] the authors have shown the rates of solution of 23 different kinds of fertilizers and some changes that take place in the first 2 weeks after these fertilizers are applied to the soil. However, no granular fertilizers were used in the previous tests, and the changes over a longer period were not studied.

Mehring, *et al.*,[4] studied the relation of particle size to action in the soil by analyzing soil to which fertilizers of varying particle size had been applied 100 days previously. They reported that, "Comparison of the determinations directly is not satisfactory since the fertilizer was mixed with different amounts of soil in each sample".

The authors sought to overcome this difficulty by a different method of approach, that is, analyzing the fertilizer residues which had been kept separate from the soil. This was accomplished by placing the fertilizers in bands about 2 inches wide and 1/8 inch thick between strips of Monel metal wire cloth buried in the soil 4 inches deep so that the fertilizers would be exposed to the natural action of the soil solution, yet could be recovered from the soil later without appreciable contamination. Three different fertilizer mixtures each in powdered form and in three sizes of granules were used in this test. Analyses were made of the residues of these fertilizers recovered from the soil after they had been in the field for 2 weeks, 16 weeks, and 1 year. The soil was Ontario loam having a pH of 6.9.

The fertilizer mixtures used in this experiment were prepared and granulated by Dr. H. W. Ross of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture at Washington. The amount of each ingredient used in preparing a ton of each fertilizer is shown in Table 1.

Each of the above formulas was prepared in powdered form and in three sizes of granules. The powdered form would pass a 40-mesh screen, the large size granules (suffix A) would pass a 4-mesh but not a 5-mesh screen, the medium size

[1]Contribution from the Divisions of Vegetable Crops and Chemistry, New York State Agricultural Experiment Station, Geneva, N. Y. Approved for publication by the Director as Journal Paper No. 220. September 15, 1937. Also presented before the Fertilizer Section American Chemical Society, Rochester, N. Y., September 10, 1937. Received for publication October 11, 1937.

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[3]SAYRE, C. B., and CLARK, A. W. Rates of solution and movement of different fertilizers in the soil and the effects of the fertilizers on the germination and root development of beans. N. Y. State Agr. Exp. Sta. Tech. Bul. 231. 1935.

[4]MEHRING, A. L., WHITE, L. M., ROSS, W. H., and ADAMS, J. E. Effects of particle size on the properties and efficiency of fertilizers. U. S. D. A. Tech. Bul. 485. 1935.

TABLE 1.—*Amount of ingredients in fertilizers used.*

Material	No. 243, 5–20–5, lbs.	No. 244, inorganic N, 5–10–5, lbs.	No. 245, organic N, 5–10–5, lbs.
Superphosphate 19.6.	640	816	816
Treble superphosphate 46.7%.	588	86	86
Ammonia	60	30	30
Ammonium sulfate 20.8%	192	288	192
Sodium nitrate 16.3%.	61	92	61
Cottonseed meal 7.2%	0	0	347
Muriate of potash 57.7%	173	173	173
Dolomite	286	340	286
Filler (sand)	0	175	9
Total.	2,000	2,000	2,000

granules (suffix B) would pass a 5-mesh but not a 10-mesh screen, while the small granules (suffix C) would pass a 10-mesh screen but not a 20-mesh screen.

Repeated trials proved that it was impossible to recover fertilizers in powdered form that had been in direct contact with the soil without varying and rather large admixtures of soil. In previous tests,[6] fertilizers had been placed between strips of cheesecloth in the soil, but it was found that the cheesecloth disintegrated after about 3 weeks, particularly if organic fertilizers were used. Consequently in the tests reported on here the fertilizers were placed in the soil between strips of Monel metal wire cloth because it was thought this metal cloth would resist the corrosive action of the soil and fertilizers for a long time. This metal cloth was made of 0.006 inch Monel metal wire woven in a 60×50 mesh. It was very flexible and water passed through it readily.

Six lots of each size of each fertilizer were placed between the metal cloth strips buried 4 inches deep in the soil in the field. After 2 weeks, 16 weeks, and 1 year two lots of each fertilizer were removed from the soil and analyzed separately. The fertilizers were placed in the field in May, 1936. The 16-week period covered the normal growing season of many vegetable crops. The analyses of the original fertilizers and of their residues recovered from the soil after 2, 16, and 52 weeks are given in Table 2, which shows the average analyses of two lots of each fertilizer. There was very close agreement in the analyses of the duplicate lots. All analyses were made by the junior author and his associates, Messrs. Kokoski, Willits, and Norton of the Fertilizer Control Laboratory.

RESULTS

Although powdered fertilizers could not be cleanly recovered after being in direct contact with the soil, it was possible after a great deal of careful and tedious work with tweezers to recover granulated fertilizer that had been in intimate contact with the soil. Two granulated 5–10–5 fertilizers, *viz.*, No. 244B having all its nitrogen in mineral form and one No. 245B in which 25% of its nitrogen was in organic form, were thus recovered and analyzed. These had been placed in the soil without any strips of metal cloth but were in direct contact with the soil and were recovered after 14 weeks in the soil and the analyses of these residues are also given in Table 2.

[6]See footnote 3.

TABLE 2.—*Analyses of powdered and granulated fertilizers recovered from the soil.*

Material	N, %	Total P_2O_5, %	Insol. P_2O_5, %	Avail. P_2O_5, %	Water-sol. P_2O_5, %	K_2O, %
No. 243A: 5-20-5 granulated 4 to 5-mesh	4.88	20.73	0.23	20.50	10.55	5.17
Residue after 2 wks. in soil*	0.39	19.00	1.64	17.36		1.00
Residue after 16 wks. in soil†	0.34	20.32	2.02	18.29		0.96
Residue after 1 yr. in soil†	0.09	15.63	1.59	14.04		0.35
No. 243B: 5-20-5 granulated 5 to 10-mesh	5.00	20.31	0.22	20.09	9.86	4.96
Residue after 2 wks. in soil*	0.38	18.95	1.42	17.53		1.06
Residue after 16 wks. in soil†	0.31	20.50	1.95	18.54		0.96
Residue after 1 yr. in soil†	0.11	13.08	0.84	12.24		0.36
No. 243C: 5-20-5 granulated 10 to 20 mesh	5.11	20.55	0.20	20.35	9.80	4.81
Residue after 2 wks. in soil*	0.40	19.65	1.52	18.13		1.22
Residue after 16 wks. in soil†	0.22	20.23	1.84	18.41		1.09
Residue after 1 yr. in soil†	0.12	15.69	1.10	14.50		0.56
No. 243: 5-20-5 powdered	5.18	20.93	0.73	20.20	10.43	5.01
Residue after 2 wks. in soil*	0.30	18.00	1.82	16.18		0.69
Residue after 16 wks. in soil†	0.27	17.67	0.74	16.93		0.84
Residue after 1 yr. in soil†	0.16	16.68	0.55	16.13		0.55
No. 244A: 5-10-5 granulated 4 to 5-mesh	5.28	10.38	0.03	10.35	4.83	5.04
Residue after 2 wks. in soil*	0.21	11.60	0.62	10.98		1.12
Residue after 16 wks. in soil†	0.08	12.16	0.99	11 16		1.01
Residue after 1 yr. in soil†	0.09	12.82	2.08	10.74		0.22
No. 244B: 5-10-5 granulated 5 to 10-mesh	4.92	10.45	0.03	10.42	4.58	5.11
Residue after 2 wks. in soil*	0.20	9.90	0.62	9.28		0.80
Residue after 14 wks. in soil‡	0.09	11.26	1.53	9.73		0.16
Residue after 16 wks. in soil†	0.07	11.49	0.84	10.64		0.80
Residue after 1 yr. in soil†	0.10	10.77	1.66	9.11		0.23
No. 244C: 5-10-5 granulated 10 to 20-mesh	5.30	10.60	0.05	10.55	4.60	5.25
Residue after 2 wks. in soil*	0.21	10.13	0.68	9.45		0.88
Residue after 16 wks. in soil†	0.08	11.27	0.54	10.73		0.60
Residue after 1 yr. in soil†	0.10	9.64	1.34	8.30		0.20
No. 244: 5-10-5 powdered	5.10	10.66	0.08	10.58	4.93	5.17
Residue after 2 wks. in soil*	0.20	8.63	0.44	8.19		0.62
Residue after 16 wks. in soil†	0.12	8.75	0.11	8.64		0.40
Residue after 1 yr. in soil†	0.10	8.14	0.10	8.04		0.28
No. 245A: 5-10-5 granulated 4 to 5-mesh	5.06	10.57	0.07	10.50	5.78	5.67
Residue after 2 wks. in soil*	1.22	10.15	1.42	8.73		1.86
Residue after 16 wks. in soil†	0.65	11.37	2.29	9.09		0.87
Residue after 1 yr. in soil†	0.77	12.67	2.81	9.86		0.25

*Fertilizer placed in cheesecloth in the soil. ‡Fertilizer in direct contact with soil.
†Fertilizer placed in Monel metal wire cloth in the soil. §Samples lost.

TABLE 2.—*Continued.*

Material	N, %	Total P_2O_5, %	Insol. P_2O_5, %	Avail. P_2O_5, %	Water-sol. P_2O_5, %	K_2O, %
No. 245B: 5-10-5 granulated 5 to 10-mesh.	4.82	10.66	0.04	10.62	5.42	5.48
Residue after 2 wks. in soil*.	1.17	9.68	—§	—§		1.90
Residue after 14 wks. in soil‡. .	0.57	10.18	0.90	9.28		0.40
Residue after 16 wks. in soil†. . .	0.64	9.95	1.21	8.74		1.27
Residue after 1 yr. in soil† . .	0.69	10.47	1.33	9.14		0.27
No. 245C: 5-10-5 granulated 10 to 20-mesh.	5.02	10.45	0.06	10.39	5.45	5.31
Residue after 2 wks. in soil*. . .	1.01	8.75	—§	—§		0.96
Residue after 16 wks. in soil†. . .	0.71	10.18	1.17	9.02		0.61
Residue after 1 yr. in soil†. . . .	0.70	8.72	1.16	7.56		0.21
No. 245: 5-10-5 powdered.	5.25	10.60	0.05	10.55	5.98	5.70
Residue after 2 wks. in soil*. . . .	1.04	9.43	—§	—§		—§
Residue after 16 wks. in soil†. .	0.67	10.22	0.48	9.74		0.43
Residue after 1 yr. in soil†	0.65	10.11	0.44	9.67		0.33

*Fertilizer placed in cheesecloth in the soil.
†Fertilizer placed in Monel metal wire cloth in the soil.
‡Fertilizer in direct contact with soil.
§Samples lost.

The analyses of these two fertilizers are especially significant and yield considerable information regarding the solubility of these fertilizer ingredients and the changes that take place in the granular fertilizers after they have been mixed with the soil.

Considering first fertilizer No. 244B in which all of the nitrogen was in inorganic form, practically all of the nitrogen soon dissolved out of the fertilizer granule. This fertilizer which originally contained 4.92% of nitrogen showed only 0.09% nitrogen after being mixed with the soil 14 weeks. On the other hand, fertilizer No. 245B in which 25% of the nitrogen was in organic form showed a much less rapid loss of nitrogen. Originally this fertilizer contained 4.82% nitrogen and after being mixed with the soil 14 weeks the fertilizer granules still contained 0.57% of nitrogen.

The percentage of available phosphoric acid[6] remaining in these granulated fertilizers after they had been mixed with the soil was remarkably high when it is considered that this Ontario loam soil has a high capacity for phosphorus fixation. These fertilizers that originally contained 10.42% and 10.62% available P_2O_5 still contained 9.73% and 9.28% available P_2O_5, respectively, after the granules had been mixed with the soil for 14 weeks. The percentage of insoluble P_2O_5 in these fertilizers increased considerably after they were mixed with the soil. Originally they contained only 0.03% and 0.04% insoluble P_2O_5 but after being mixed in the soil 14 weeks these percentages had increased to 1.53% and 0.90%, respectively. This increase in *percentage* of insoluble P_2O_5 was probably due to two causes. First,

[6]As determined by the neutral ammonium citrate method of the A. O. A. C.

the loss of the soluble ingredients of the fertilizer granules would of itself increase the percentage of insoluble material remaining. Secondly, reversion of the soluble P_2O_5 by reaction with the soil would also increase the total amount and percentage of insoluble P_2O_5. To the authors it seemed particularly noteworthy that there was such a large percentage of available P_2O_5 remaining in the fertilizer granules after they had been mixed with soil in the field for 14 weeks.

Since the potash in fertilizers is required by law to be water-soluble, it is to be expected that the potash would dissolve out of the fertilizer granules soon after they had been mixed with the soil. Analyses of the fertilizer residues recovered from the soil showed that the potash had dissolved out of the fertilizer granules quite rapidly. Originally fertilizer No. 244B contained 5.11% K_2O (Table 2), but after being mixed with soil in the field for 14 weeks there was only 0.16% K_2O remaining in the fertilizer granules. The potash did not dissolve out so rapidly when the fertilizer was placed in concentrated bands between Monel metal cloth and buried in the soil. In this case 0.8% K_2O remained in the fertilizer residue after it had been in the soil for 16 weeks.

Analyses of fertilizer 245B showed similar results with the potash. Originally this fertilizer contained 5.48% K_2O and after it had been mixed in intimate contact with the soil for 14 weeks only 0.4% K_2O remained in the residue of the fertilizer granules. Where this fertilizer had been placed in bands between Monel metal wire cloth in the soil for 16 weeks, however, there was 1.27% K_2O still remaining in the fertilizer residue. Tests have shown that there is a rapid rate of fixation of potash in this soil and apparently this rate of fixation was retarded by placing the fertilizer in bands between the metal cloth.

Aside from the significant difference in the rate of fixation of potash just discussed, there was a rather close similarity in the analyses of the residue of fertilizer 244B where it was mixed with the soil for 14 weeks and then the granules recovered as compared with the same fertilizer placed in bands between Monel metal wire cloth, buried in the soil 16 weeks, and then recovered for analysis. Similarly, with fertilizer No. 245B, there was a close correlation between the analysis of the fertilizer residue that had been mixed with the soil and that that had been placed in the metal cloth in the soil. Since each of these fertilizers showed this close correlation, it seems reasonable to expect that the analyses (Table 2) of the residues of each of the fertilizers that had been placed between the Monel metal wire cloth buried in the soil would give a rather close approximation of the changes that occur in fertilizers when they are mixed with the soil. It is probable, however, that with the powdered or more finely divided fertilizers there would be a more rapid rate of fixation of phosphoric acid and of potash when these were mixed through the soil than where they were placed in concentrated bands between metal cloth buried in the soil. Judging from the correlation in the analyses of fertilizers 244B and 245B, it seems probable that the analyses (Table 2) of the fertilizers recovered from the metal bands are a close approximation of the changes that take place in the soil when fertilizers are applied in band applications in field practice.

From the analyses of fertilizers No. 243 and 244 in which the nitrogen was wholly in inorganic form derived from ammonia, ammonium sulfate, and sodium nitrate, it can be seen that the inorganic nitrogen passed out of the fertilizer bands into the soil very rapidly regardless of the size of the granules (Table 2). Fertilizer No. 243 contained originally 4.88%, 5.00%, 5.11%, and 5.18% of nitrogen in the three sizes of granules and in the powdered form, respectively. Yet after only 2 weeks in the soil the percentage of nitrogen remaining in the residues of this fertilizer was 0.39, 0.38, and 0.40 in the granulated forms and only 0.30 in the powdered form. Thus it is evident that over 92% of the inorganic nitrogen passed out of the fertilizer bands into the soil within 2 weeks. The little remaining nitrogen then disappeared less rapidly as there was a very slight further loss in 16 weeks. After 1 year in the soil the amount of nitrogen remaining in the fertilizer residue was negligible, being 0.16% and less in the different samples.

Fertilizer No. 244 showed a similar rapid movement of nitrogen into the soil. Originally the different lots of this fertilizer contained 5.28%, 4.92%, 5.30%, and 5.10% of nitrogen, but after 2 weeks in the soil all of these lots showed only 0.20% and 0.21% of nitrogen remaining in the fertilizer residue. There was no appreciable difference in the rate of solution of the inorganic nitrogen from the granulated or powdered forms.

The organic nitrogen passed into the soil more slowly as shown in the analyses of fertilizer No. 245 (Table 2). In this 5–10–5 fertilizer one-fourth of the nitrogen was in organic form (cottonseed meal, Table 1). Samples of this fertilizer showed that it originally contained 5.06%, 4.82%, 5.02%, and 5.25% of total nitrogen in the three granulated sizes and in the powdered form, respectively. After being in the soil 2 weeks the residues of these fertilizers analyzed 1.22%, 1.17%, 1.01%, and 1.04% of nitrogen, respectively. Since in the other fertilizers (Nos. 243 and 244) it was found that 92% or more of inorganic nitrogen passed out of fertilizer bands into the soil within 2 weeks and since there was only about 1.25% of organic nitrogen in fertilizer No. 245 originally, it is evident that most of the organic nitrogen was still in the fertilizer residues after 2 weeks in the soil.

After 16 weeks in the soil the four samples of fertilizer No. 245 showed 0.65%, 0.64%, 0.71%, and 0.67% of nitrogen remaining in the residues of these fertilizers. This indicates that approximately half of the organic nitrogen still remained in the fertilizer bands. Apparently the organic nitrogen was retained in the larger granules slightly longer than in the powdered fertilizer as shown by the analyses after the fertilizers had been in the soil for 2 weeks. However, after 16 weeks in the soil, the amount of nitrogen remaining in the fertilizer was remarkably uniform regardless of the size of the granule as shown by the figures just quoted. After 1 year in the soil there were no additional significant changes in the percentage of nitrogen remaining in the fertilizer residues. In two cases (No. 245A and 245B, Table 2), there was a slight increase in the *percentage* of nitrogen remaining in the fertilizer residue. This was probably due to a more rapid loss of other soluble ingredients which would automatically increase the percentage of the remaining ingredients.

Potash disappeared from the fertilizer bands quite rapidly regardless of the size of the granules. The granulated fertilizers however, retained the potash a little longer than the powdered forms. Within 2 weeks 60% to 80% of the soluble potash had disappeared from the fertilizer bands in the soil, with the fertilizers containing organic nitrogen retaining the potash longer. However, less than one-fifth of the potash remained in the fertilizer bands after 16 weeks in the soil and half of this disappeared by the end of the year. For example, in fertilizer No. 243A, these large granules (4- to 5-mesh) originally contained 5.17% of potash. After 2 weeks in the soil there was only 1.00% of potash remaining in the residue of a band of this fertilizer; after 16 weeks, 0.96%; and after 1 year, 0.35%. This fertilizer in smaller sized granules (Nos. 243B and 243C, Table 2) showed a similar rapid movement of potash out of the fertilizer bands. The rate of movement of the potash was slightly more rapid from the powdered fertilizer. In this case (No. 243), the fertilizer originally contained 5.01% of potash. After 2 weeks in the soil only 0.69% of potash remained in the fertilizer residue.

The movement of potash from fertilizers Nos. 244 and 245 has already been discussed and it was shown that the potash disappeared from the fertilizer granules more rapidly where they were mixed through the soil than where the fertilizers were placed in bands between wire cloth in the soil.

Analysis of the fertilizers before they were placed in the soil showed that the water-soluble phosphoric acid was greater in the mixtures containing larger amounts of treble superphosphate (compare fertilizers No. 243 and 244, Tables 1 and 2). The 5-20-5 (No 243) fertilizer in which 588 pounds of treble superphosphate was used per ton, contained 10.43% water-soluble phosphoric acid, or more than twice as much as the 4.93% water-soluble phosphoric acid in the 5-10-5 mixture (No. 244) in which 86 pounds of treble superphosphate were used per ton. Comparing the two 5-10-5 formulas (fertilizers Nos. 244 and No. 245) both of which contained equal amounts of treble superphosphate and also of ordinary superphosphate, it will be seen from Table 2 that No. 244, the fertilizer containing more dolomite and more ammonium sulfate and nitrate of soda but no cottonseed meal, had 4.93%, or about five-sixths as much water-soluble phosphoric acid, as the 5.98% found in the fertilizer containing more organic nitrogen and less dolomite and ammonium sulfate. With all three fertilizers it is interesting to note that the percentage of water-soluble phosphoric acid was substantially the same in the three sizes of granules as in the powdered forms. Evidently the granulating process did not affect the water solubility of the phosphoric acid. The amount of water-soluble phosphoric acid is thought by some agronomists to be an important factor in the relative value of a fertilizer in increasing crop yields.

The percentage of available phosphoric acid found in the residue of each fertilizer band was remarkably high after an entire year in the soil and there was no consistent relation between the size of the fertilizer granule and the percentage of available phosphoric acid. Before the fertilizers were placed in the soil there was no significant difference

in the percentage of available phosphoric acid nor of insoluble phosphoric acid between the powdered and granulated fertilizers of the same formula. Consequently, it would seem that the granulating process did not affect the availability of the phosphoric acid. However, in the residues of the fertilizers recovered from the soil, there was a marked increase in the percentage of insoluble phosphoric acid and this increased with the increase in size of the granules. This is evident in all three fertilizer mixtures (Table 2).

It should be noted that the fertilizers were placed in bands in the soil which would tend to prevent rapid reversion of the phosphoric acid as compared with the reaction if fertilizers had been mixed through the soil, particularly the powdered forms. Also, the metal cloth prevented intimate contact with the soil, but the fertilizers were exposed to the natural action of the soil solution. Hence, since there was a close correlation between the analyses of the two granulated fertilizers that had been mixed through the soil and the analyses of the same fertilizers recovered from the bands between Monel wire cloth placed in the soil, it is felt that the analyses reported in Table 2 give a good indication of the rates of solution of the fertilizer ingredients when fertilizers are placed in bands in direct contact with the soil.

THE PRODUCTIVITY OF ALFALFA AS RELATED TO MANAGEMENT[1]

L. F. GRABER AND V. G. SPRAGUE[2]

CUTTING or pasturing the fall growth of alfalfa (*Medicago sativa*) in Wisconsin is usually quite hazardous with respect to winter survival. In 1936, the hay crop was short because of excessive summer heat and drouth, and farmers generally replenished their supplies by cutting the fall growth of alfalfa resulting from generous autumnal rainfall. This proved quite harmful in 1937 with respect to winter survival, especially where only light snows prevailed. In some instances, however, ice sheets and cold caused almost complete killing of stands, where neither fall cutting nor pasturing were practiced. In other regions, with good snow cover, late fall cutting or pasturing was not detrimental. Such responses are similar to those observed at rather frequent intervals during the past 25 years of work in the expansion of alfalfa culture in Wisconsin.

Occasionally, it is claimed that a winter cover of tall alfalfa stubble is harmful rather than helpful in maintaining the productivity of alfalfa because it may delay early spring growth by providing a longer duration of the deeper snow cover and slower rise in soil temperatures. Such retardation is usually desirable with respect to security of stand even though a delayed spring growth may present a very unfavorable visual contrast with the early vigor of alfalfa that survives without the presence of fall stubble. The prolongation of harmful sheets of ice by fall stubble is not of common occurrence, but when it occurs, it is highly disadvantageous with respect to survival.

The presence of dead stubble in the first growth of the following year, while usually not of serious consequence, may lower the quality of hay and enhance the likelihood of certain foliar diseases. For a number of years, the senior author has burned off old stubble in late winter or early spring while the soil was still frozen or before spring growth had started. This improves the quality of the hay not only because of the destruction of the old stubble, but also because in certain years it appears to reduce foliar diseases, such as the black stem disease (Ascochyta) and leaf spots (Pseudopeziza). However, such observational evidence is not sufficient to warrant a general recommendation of a practice which would involve fire hazards, which might amplify subsequent heaving, and which might result in previous winter injury being attributed to it. It is merely mentioned here to call attention to the objectionable features of fall stubble since the value of autumnal growth, and the winter cover it provides, is amply supported by field observations in Wisconsin and by the experimental evidence presented in this paper.

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In 1931 a series of cutting trials were begun to measure the effect of fall removals of top growth and also early cutting of the first growth on the productivity of hardy Canadian variegated alfalfa. Late winter or early spring burning of winter cover was not used to eliminate the stubble in these trials. It was hoped, at the time the trials were begun, that winter conditions might not be so differential as to cause a spontaneous and heavy loss of stand for any one unfavorable cutting treatment. Such hopes were fully realized during the following three years. In Part I of this paper only the data pertaining to the removals of fall growth of alfalfa given uniformly deferred summer cuttings will be presented. In Part II, the responses from early cutting of the first growth will be discussed in their relation to leafhopper injury, fall cutting treatments, and fertility levels.

I. REMOVALS OF FALL GROWTH

CUTTING TREATMENTS

The productivity of alfalfa was measured at two levels of fertility in field trials on the University Farm at Madison, Wisconsin. A well-established, thick, and uniform stand of Canadian variegated alfalfa, sown June 27, 1930, was given three cutting treatments during 1931, 1932, and 1933 as follows: (A) Two deferred (near full bloom) summer cuttings and no fall cutting; (B) two deferred (near full bloom) summer cuttings and one late fall cutting; and (C) two deferred (near full bloom) summer cuttings, one early fall and one late fall cutting.

In 1934, only two uniformly deferred summer cuttings were taken. All the above cutting treatments provided full opportunity for storage of reserve foods during the summer period and for the elimination of noteworthy injury from leafhoppers (*Empoasca fabae*). Treatment A provided for maximum fall storage and abundant winter cover. Treatment B provided for maximum fall storage, but the winter cover was nearly all removed after growth had ceased in late October or early November. Only about 1½ inches of the basal uncut portions of the stems remained after cutting and harvest. Treatment C was planned to reduce food storage by cutting during the middle of the fall storage period (late September and early October) when not only was photosynthesis and storage interrupted, but reserves were subsequently utilized for new fall growth. This new fall growth was removed in late October or early November on the same dates and in the same manner as for fall cutting treatment B. In treatment C, the opportunity for fall storage was greatly reduced, fall hardening of the overwintering parts was retarded and vegetative cover was nearly all eliminated. All cuttings were made with a field mower with the bar set about 1½ inches above the soil surface and the cut alfalfa was removed from the plats in all cases.

These trials (A, B, and C) were conducted on alternate halves of long, narrow, quadruplicated plats with limited randomization. They were 1/70 and 1/100 acre in size. The remaining halves received an early summer cutting treatment (AA, BB, and CC) the results of which are reported in part II of this paper. Borders were removed and green weights of the remaining forage were taken shortly after cutting. These were reduced to oven-dried weights of alfalfa hay by moisture determinations on representative samples. Where they appeared of any consequence, weeds and old stubble appearing in the hay were deducted from the gross yields. Such determinations of yields of oven-dried weed-free hay are reported in Table 3 and are shown graphically in Figs. 1 and 2.

TWO LEVELS OF FERTILITY

Two fertility levels were provided by fertilization and by selection of plats where the fertility responses had been measured previously by field trials with alfalfa. Where fertilization was necessary to raise the fertility level, 20% superphosphate was applied at the rate of 800 pounds per acre and muriate of potash (50% K_2O) at the rate of 300 pounds per acre. These applications were made in April, 1930, and were incorporated into the surface 3 inches of soil by cultivations prior to the seeding which was done on June 27, 1930. For convenience

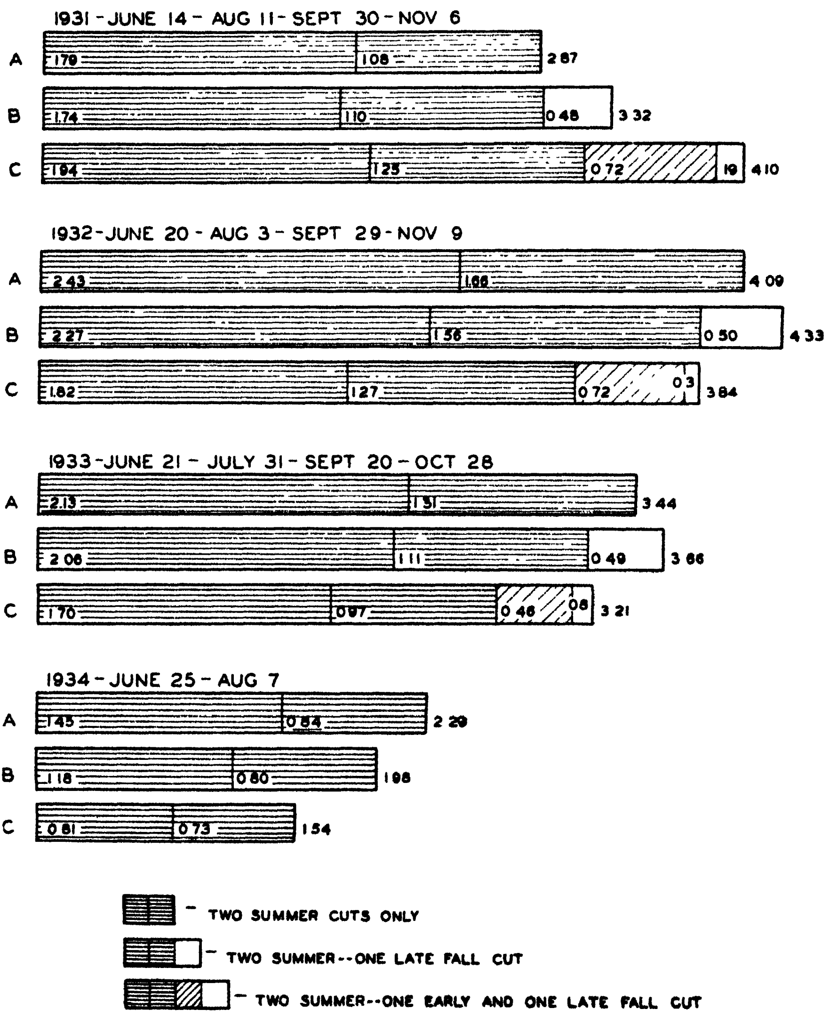

FIG. 1.—Two deferred summer cuttings with three fall cutting treatments of alfalfa grown on soil of optimum fertility.

(Yields in tons per acre of oven-dried, weed-free hay.)

in expression the two levels of fertility are referred to as optimum and moderately low.

Randomized samplings of soil (Miami silt loam) in each plat were taken by Prof. E. J. Graul of the Soils Department of the University of Wisconsin and were analyzed in February, 1933, for available phosphorus (P_2O_5) and potash (K_2O) and for acidity. The results are shown in Table 1.

The surface soil in each plat showed a medium minus degree of acidity—about pH 5.8. No lime was applied prior to or during the course of these trials. The areas had provided from fair to good yields of alfalfa hay in accordance with fertility variations for 6 years previous to this trial. The topography of this experimental area was fairly level, although there was sufficient slope to provide for moderately good surface runoff of excess moisture. The plats high in fertility had a little higher elevation and slightly better surface drainage.

WEATHER CONDITIONS

Since alfalfa has a very high water requirement and yields are much dependent on moisture supply, the regional rainfall which occurred during the five growing seasons is given in Table 2 as taken from the records of the U. S. Weather Bureau located about 2½ miles from the experimental plats.

TABLE 1.—*Pounds of available P_2O_5 and K_2O per acre in the surface 6 inches of soil on which alfalfa was grown with various cutting treatments.*

Treatment, 4 plats averaged	P_2O_5, lbs.	K_2O, lbs.
Optimum Level of Fertility		
A and AA	41	198
B and BB	30	154
C and CC	40	194
Moderately Low Level of Fertility		
A and AA	25	103
B and BB	23	103
C and CC	26	127

TABLE 2.—*Rainfall in inches at Madison, Wisconsin.*

Month	1930	1931	1932	1933	1934
April	2.95	1.97	1.04	3.75	1.08
May	4.23	1.74	3.67	9.35	0.82
June	6.60	3.05	3.15	1.64	2.77
July	2.84	2.10	4.06	3.33	3.42
August	1.58	5.19	2.51	2.57	2.21
September	4.79	7.17	0.18	3.58	4.25
October	1.63	3.11	3.68	1.48	2.27
Total	24.62	24.33	18.29	25.70	16.82

The year the alfalfa plats were seeded (1930) was one of abundant and well-distributed rainfall from April to October, inclusive, and very good uniform stands were obtained. The alfalfa was not cut that season. The moderate deficiency in rainfall during April and May,

1931, was amply offset by the abundant reserves of subsoil moisture from 1930. Only in the year of 1934 was it extremely hot and dry from April to August and this is reflected in the seasonal yields of alfalfa hay. Fortunately no severe winter conditions prevailed that would seriously injure well-managed hardy alfalfa. In general, however, the winters of 1930, 1931, 1932, and 1933 were sufficiently adverse to

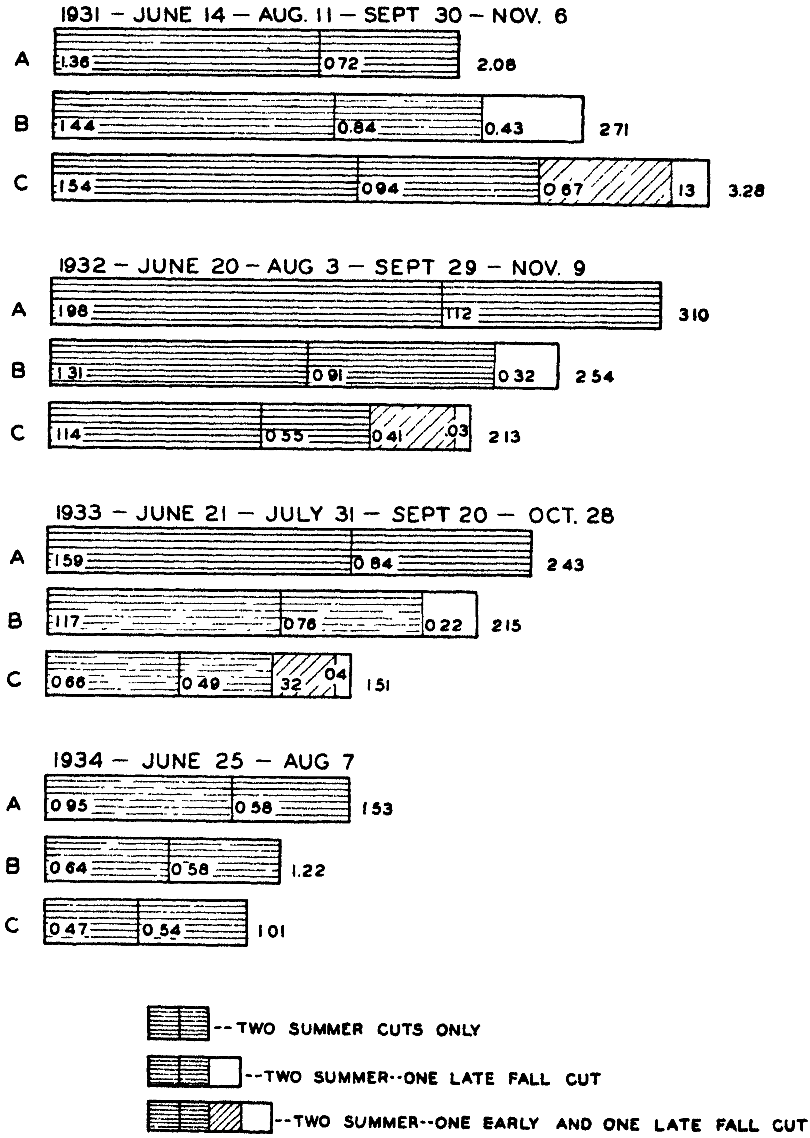

FIG. 2.—Two deferred summer cuttings with three fall cutting treatments of alfalfa grown on soil moderately low in fertility.
(Yield in tons per acre of oven-dried, weed-free hay.)

reflect considerable loss of alfalfa given unfavorable management for winter survival and subsequent productivity.

FALL CUTTING LOWERS PRODUCTIVITY

Fall cuttings reduced subsequent yields (Figs. 1 and 2) particularly when both food storage was reduced and fall cover removed (treatment C). A precise measure of the residual effects of 3 years (1931, 1932, and 1933) of the fall cutting treatments B and C compared with no fall cutting, treatment A, is reflected in the yields of the two annual and uniformly deferred summer cuttings of 1932, 1933, and 1934. These are given in Table 3. It will be noted that with the optimum level of fertility, one late fall cutting annually (B) for 3 years reduced the total subsequent summer yields for 3 years by a total of only 0.84 ton per acre, or 8.5%, whereas two fall cuts (C) resulted in 2.52 tons less hay, or a loss of 25.7%. Where the soil was moderately

TABLE 3.—*The influence of fall cutting treatments in 1931, 1932, and 1933 on the productivity of alfalfa with early and deferred cuttings of the first crop in 1932 and 1933, expressed in yields of oven-dried, weed-free alfalfa hay in tons per acre.*

Cutting treatment	Yields from two summer cuts in 1932, 1933, and 1934			Total yields, 1931–34, incl.			Total yields, 1934	
	Total	Loss		All summer cuts	All fall cuts	All cuts	Two cuts	% increase with optimum fertility
		Tons	%					
				Optimum Fertility				
A	9.82	—	—	12.09	—	12.09	2.29	49.6
B	8.98	0.84	8.5	11.82	1.47	13.29	1.98	62.3
C	7.30	2.52	25.7	10.49	2.20	12.69	1.54	52.4
				Moderately Low Fertility				
A	7.06	—	—	9.14	—	9.14	1.53	—
B	5.37	1.69	23.9	7.65	0.97	8.62	1.22	—
C	3.85	3.21	45.5	6.33	1.60	7.93	1.01	—
				Optimum Fertility				
AA	7.27	—	—	10.14	—	10.14	1.69	42.0
BB	5.81	1.46	20.1	8.66	1.07	9.73	1.27	84.0
CC	4.21	3.06	42.1	7.39	1.68	9.07	0.93	55.0
				Moderately Low Fertility				
AA	5.73	—	—	7.81	—	7.81	1.19	—
BB	3.32	2.41	42.0	5.59	0.78	6.37	0.69	—
CC	2.15	3.58	62.5	4.63	1.35	5.98	0.60	—

low in fertility the losses in summer productivity were much greater, treatment B reducing the subsequent summer tonnage 23.9%, or 1.69 tons, and treatment C, 45.5%, or 3.21 tons, compared with A in which fall cutting was not practiced.

The total yields of the two summer cuttings (treatment A) and the summer and fall cuttings of treatments B and C for the 3 years (1931, 1932, and 1933) in which fall cuttings were made, were 10.4, 11.31, and 11.15 tons, respectively. The total yields from treatments B and C were slightly larger (8.7% and 7.2%) than those obtained from treatment A where the fall growth was not a part of the total yields, being allowed to remain as winter cover. This comparison applies to soil with the optimum level of fertility. With alfalfa growing on soil moderately low in fertility such yields were 7.61 tons for A, 7.40 tons for B, and 6.92 tons for treatment C. These yields were slightly lower (2.7% and 9.0%) with cuttings of the fall growth than without.

The total yields during the 4-year period (1931–34) for all cuts of treatments A, B, and C (both summer and fall cuttings in case of B and C) did not vary widely when the fertility level was optimum (Table 3), but with moderately low fertility treatment C produced 1.21 tons, or 13.2%, less than A and B produced 0.52 ton, or 5.7%, less than A for the 4-year period.

Fertility levels had the greatest influence on the productivity of alfalfa as measured by total yields over the 4-year period. With a moderately low level of fertility, cutting treatment A produced 3.55 tons, or 28%, less hay; B, 4.67 tons, or 35.1%, less; and C, 4.76 tons, or 37.5%, less than the total yields obtained from the comparable series on the soil of optimum fertility.

The yield data from the two deferred summer cuttings and the total yields clearly demonstrate that alfalfa growing under very favorable soil conditions with respect to fertility and surface drainage is more likely to maintain productivity under adverse fall cutting treatments.

SUMMARY ON EFFECT OF FALL CUTTINGS

The autumnal growth of alfalfa provides for food storage in and hardening of the over-wintering parts of alfalfa and for winter cover in the form of stubble which are important factors in the effective winter survival and subsequent productivity of alfalfa in Wisconsin. A comparison was made of such a favorable over-wintering condition in hardy Canadian variegated alfalfa with one where the fall growth was removed by cutting late and thus not reducing autumnal storage, but eliminating most of the vegetative cover and with one where autumnal food storage was reduced and the stubble cover was removed by two fall cuttings.

Removal of vegetative cover in late autumn for 3 years without reducing fall storage of reserve foods (very late fall cutting) lowered the productivity of alfalfa as measured by two deferred cuttings in three subsequent and consecutive summers, 8.5% on soil of optimum fertility and 25.7% on soil moderately low in fertility.

Elimination of vegetative cover and the lowering of fall storage of food (midfall and late fall cutting) for 3 years reduced the summer

productivity of alfalfa in three subsequent and consecutive summers 23.9% on the soil of optimum fertility and 45.5% on the soil moderately low in fertility.

While abundant stubble cover may, at times, be objectionable because the presence of old alfalfa in the first growth of the following year may lower somewhat the quality of hay, increase foliar diseases, and retard early spring growth, the benefits in terms of subsequent productivity and duration from such winter cover, including concomitant maximum autumnal storage of food and winter hardening, overcome, to a large degree, such disadvantages.

When the utilization of the fall growth of alfalfa becomes a necessity, cutting or pasturing in late autumn after food storage has occurred would seem much less harmful with respect to survival and subsequent productivity than earlier removals of fall growth.

Alfalfa withstands unfavorable fall cutting treatments much more effectively when grown with an optimum level of soil fertility and good surface drainage.

PART II. EARLY VS. DEFERRED CUTTING OF THE FIRST GROWTH OF ALFALFA

The time and frequency of cutting alfalfa are influenced by so many variable factors, such as moisture supply, soil conditions, length of the growing season, intensity and duration of solar radiation, severity of the winter seasons, snow covering, etc., that regional cutting schedules differ very widely. An insect, the leafhopper (*Empoasca fabae*), has a direct bearing on the time of cutting the first crop in Wisconsin. Under field conditions in this state, leafhoppers rarely cause serious injury to the first growth or the fall growth of alfalfa, but if the adults lay eggs in the young second growth, severe damage may occur from large populations of resulting nymphs.

Graber and Sprague[3] have shown that with early cutting in June leafhoppers stunted and yellowed the second growth of alfalfa, whereas in adjacent areas where the first cutting was deferred for 12 days, injury by these insects was effectively controlled. They found a 28-fold increase in the populations of leafhopper nymphs in the second growth (July) of alfalfa in 24 plats cut on June 9, 1933, compared with 24 adjacent and alternating plats cut 12 days later on June 21, 1933. With such deferred cutting, the adults completed egglaying in the first growth and died and the eggs were removed in the hay, thus reducing infestations of the following growth. With earlier cutting of the first growth, egg deposition not being completed was continued in the succeeding growth of young alfalfa, resulting in large numbers of nymphs which hatched in July and caused severe stunting and yellowing of the second growth. Such findings were made on the series of plats described in parts I and II.

[3]GRABER, L. F., and SPRAGUE, V. G. Cutting treatments of alfalfa in relation to infestations of leafhoppers. Ecology, 14:48–59. 1935.

CUTTING SCHEDULES

The remaining alternate halves of the plats (1/70 to 1/100 acre) of Canadian variegated alfalfa described under treatments A, B, and C in part I of this paper were used for the early summer cutting treatments and were designated AA, BB, and CC. The dates of each cutting of treatments A, B, and C and AA, BB, and CC are given in Table 4. In 1931 and 1934 the cutting dates for A, B, and C are the same as for AA, BB, and CC, respectively. The only difference in dates of cutting of these two series occurs with the first growth of 1932 and 1933. With A, B, and C it was deferred to June 20, 1932, and June 21, 1933, when near the full bloom stage as described in part I. With AA, BB, and CC it occurred 12 days earlier, on June 8, 1932, and June 9, 1933, when the alfalfa was approximately in the tenth bloom stage.

TABLE 4.—*Cutting schedules of Canadian variegated alfalfa sown June 27, 1930, on soil of optimum fertility and soil moderately low in fertility.*

Cutting treatments		Cutting dates			
Fall	Summer (first cut)	1931*	1932	1933	1934
A	Deferred	June 14–Aug. 11	June 20–Aug. 3	June 21–July 31	June 25–Aug. 7
AA	Early	June 14–Aug. 11	June 8–Aug. 3	June 9–July 31	June 25–Aug. 7
B	Deferred	June 14–Aug. 11–Nov. 6	June 20–Aug. 3–Nov. 9	June 21-July 31–Oct 28	June 25–Aug. 7
BB	Early	June 14–Aug. 11–Nov. 6	June 8–Aug. 3–Nov. 9	June 9–July 31–Oct. 28	June 25–Aug. 7
C	Deferred	June 14–Aug. 11–Sept. 30–Nov. 6	June 20–Aug. 3–Sept. 29–Nov. 9	June 21–July 21–Sept. 20–Oct. 28	June 25–Aug. 7
CC	Early	June 14–Aug. 11–Sept. 30–Nov. 6	June 8–Aug. 3–Sept. 29–Nov. 9	June 9–July 31–Sept. 20–Oct. 28	June 25–Aug. 7

*Because of dry hot weather in May and early June, 1931, alfalfa was well blossomed on June 14 when the first cutting of all plats was taken.

In this discussion we are primarily concerned with the effect of 2 years of such early summer cutting of the first growth on the immediate and subsequent productivity when their influence is imposed on alfalfa given three fall cutting treatments and on alfalfa grown under conditions of optimum and moderately low soil fertility. The results are portrayed graphically in Figs. 1, 2, 3, and 4 and in Tables 3 and 5.

WINTER INJURY INDUCED BY FALL CUTTINGS INTENSIFIES IMMEDIATE LOSSES FROM EARLY CUTTING OF FIRST GROWTH

A matter of 12 days earlier cutting of the first growth of alfalfa in 1932 and 1933 reduced the immediate productivity of the first growth (Table 5) below that of deferred cutting from 12.3% to 28.9% (0.56

TABLE 5.—*The influence of cutting the first crop of alfalfa in the tenth bloom stage (12 days earlier than deferred cutting) for two years (1932 and 1933) on the immediate productivity of the first and second growths and on residual productivity in 1934.*

Cutting treatment	Yields of weed-free, oven-dried alfalfa hay in tons per acre									Cuttings June 25 and Aug. 7, 1934		
	First cutting 1932 and 1933	Loss		Second cutting 1932 and 1933	Loss		Total two cuts 1932 and 1933	Loss		Total 1934	Percentage residual loss from previous	
		Tons	%		Tons	%		Tons	%		Early cuttings in 1932 and 1933	Fall cuttings in 1931, 1932 and 1933
	Optimum Fertility											
A	4.56	—	—	2.97	—	—	7.53	—	—	2.29	—	—
AA	4.00	0.56	12.3	1.58	1.39	46.8	5.58	1.95	25.9	1.69	26.2	—
B	4.33	—	—	2.67	—	—	7.00	—	—	1.98	—	13.5
BB	3.23	1.10	25.4	1.31	1.36	50.9	4.54	2.46	35.1	1.27	35.8	—
C	3.52	—	—	2.24	—	—	5.76	—	—	1.54	—	32.7
CC	2.50	1.02	28.9	0.78	1.46	65.1	3.28	2.48	43.0	0.93	39.6	—
	Moderately Low Fertility											
A	3.57	—	—	1.96	—	—	5.53	—	—	1.53	—	—
AA	3.34	0.23	6.4	1.20	0.76	38.8	4.54	0.99	17.9	1.19	22.2	—
B	2.48	—	—	1.67	—	—	4.15	—	—	1.22	—	20.2
BB	1.90	0.58	23.4	0.73	0.94	56.3	2.63	1.52	36.6	0.69	43.4	—
C	1.80	—	—	1.04	—	—	2.84	—	—	1.01	—	34.0
CC	1.11	0.69	38.3	0.44	0.60	57.7	1.55	1.29	45.4	0.60	40.6	—

to 1.02 tons per acre) where the fertility level was optimum and from 6.4% to 38.3% (0.23 to 0.69 ton per acre) where the soil was moderately low in fertility. In southern Wisconsin, blossoming of alfalfa generally begins in the forepart of June, and with a favorable environment, the accumulations of dry weight are most rapid in the following two or three weeks.

Such was the definite trend of the yields in this trial, but it is particularly significant that the greatest losses of immediate productivity

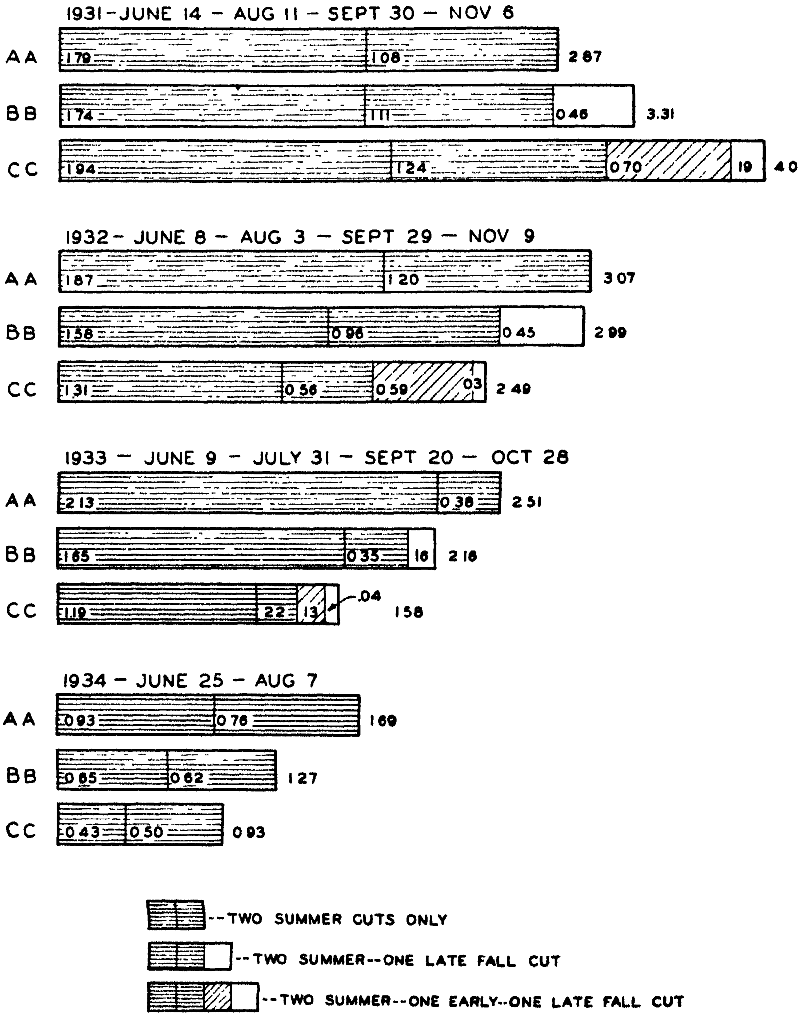

FIG. 3.—Early cutting of first growth and deferred cutting of the second growth with three fall cutting treatments of alfalfa grown on soil with optimum fertility.

(Yields in tons per acre of oven-dried, weed-free hay.)

from early cutting of the first growth in both tonnage and percentage prevailed with the alfalfa having had reduced winter cover (B and BB) and especially when not only had vegetative cover been reduced but also autumnal food storage (C and CC) of the roots. Such fall cutting treatments resulted in winter injuries which weakened and

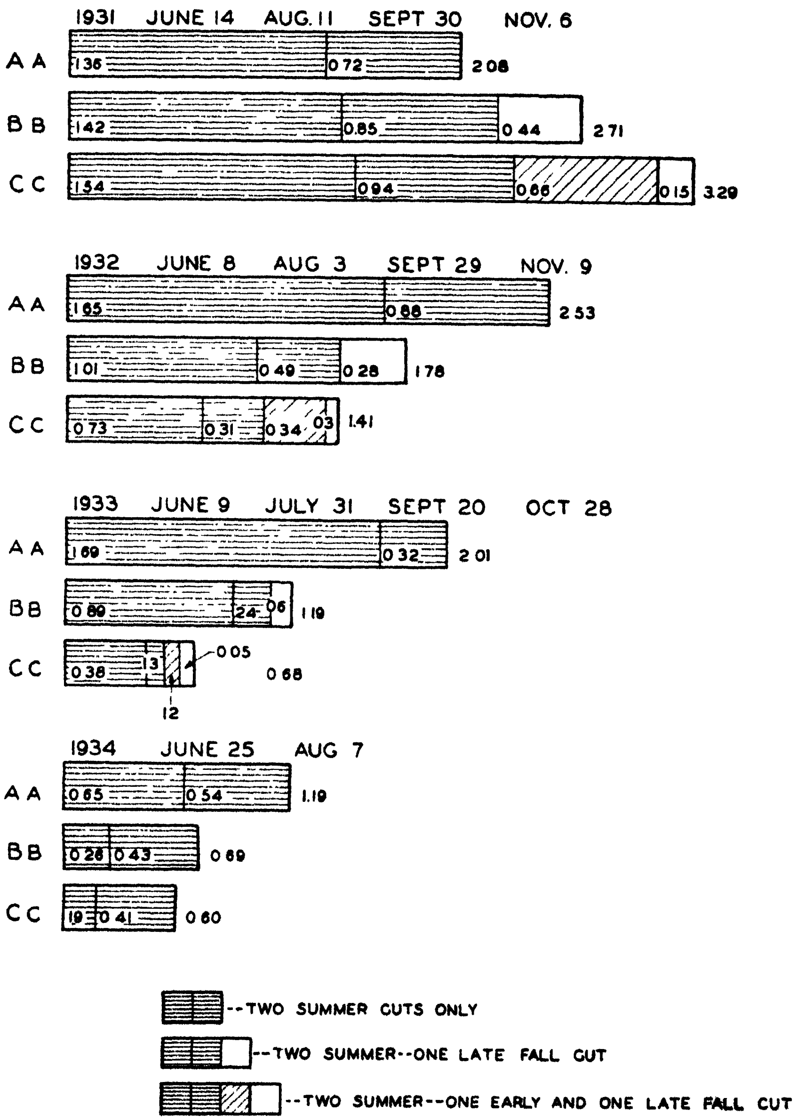

FIG. 4.—Early cutting of the first growth and deferred cutting of the second growth with three fall cutting treatments of alfalfa grown on soil moderately low in fertility.

(Yields in tons per acre of oven-dried, weed-free hay.)

retarded the succeeding growth, a condition reflected in greatly reduced yields from early cutting of the first growth.

Such findings and those relating to the productivity of the second cutting, lend great emphasis to the validity of the previous work of the senior author (Wis. Agr. Exp. Sta. Bul. 388, pp. 28–29) in which the prolongation of photosynthesis and the resultant food storage that prevails with deferred cutting of the first growth was found to be highly essential for rebuilding new root and crown tissue to replace winter-injured parts and structures.

LEAFHOPPERS INJURE SECOND GROWTH WHERE FIRST CROP WAS CUT EARLY

As is generally true with alfalfa cut for hay in Wisconsin, only the second growth was severely injured by leafhoppers in this trial. While such injury was unusually serious in 1932 and 1933 (not in 1931 or 1934), it prevailed, almost entirely in the 24 plats where the first growth had been cut 12 days earlier than the 24 adjacently alternating and comparable plats which were given deferred cutting of the first growth. In July 1932 and 1933 the plats of stunted and yellowed second-growth alfalfa, heavily infested with wingless leafhopper nymphs, were in sharp contrast to the adjacent plats of healthy second-growth alfalfa which remained relatively free from leafhopper infestations until just before the cutting stage. Then the nymphs in the infested plats had become winged adults and migrated to the healthy alfalfa. The injury from such migrations was primarily that of yellowing. Stunting was not particularly serious, since the alfalfa had already reached the cutting stage and was cut shortly after the yellowing occurred.

The productivity of the second growth (Table 5) of alfalfa in 1932 and 1933 on soil of optimum fertility was reduced from 46.8% to 65.1% (1.39 to 1.46 tons per acre) and on soil of moderately low fertility from 38.8% to 57.7% (0.76 to 0.60 ton per acre) with early cutting of the first crop. These were heavy losses and were due, primarily, to leafhopper injury. However, where alfalfa had suffered winter injuries induced by previous fall cutting treatments (BB and CC), the losses were greater on a percentage basis, indicating that early cutting of winter-weakened alfalfa would have reduced the yields of the second growth somewhat whether leafhoppers were present or not.

The magnitude of the losses in productivity of both first and second growths of alfalfa from early cutting of the first growth is also shown in Table 5 For the two years, 1932 and 1933, such losses varied from 1.95 to 2.48 tons per acre (25.9% to 43.0%) with alfalfa grown on soil of optimum fertility and from 0.99 to 1.29 tons (17.9% to 45.4%) on soil moderately low in fertility. In all cases, the percentage and tonnage reductions in yield from early cutting as compared with deferred cutting of the first growth were much larger (Tables 3 and 5) where alfalfa had suffered winter injuries induced by previous fall cutting treatments. These results are indicative of the hazards which prevail when the first growth of winter-weakened alfalfa is cut before the

plants have had sufficient opportunity to repair the injuries they have sustained and especially, in years when leafhoppers are abundant, as is often the case in Wisconsin.

It is recognized that with small experimental plats, the concentrations of leafhoppers may well have been much greater than would have prevailed in a similar comparison of early and deferred cutting on a large field scale, although with differential cutting of large fields of alfalfa in Wisconsin very severe injury in early cut portions of such fields has been observed. However, such damage was generally most intense at the line of juncture between the early and deferred cutting of the first crop.

RESIDUAL EFFECTS IN 1934

In 1934, all plats were given two uniformly deferred summer cuttings. The first cutting was taken June 25 and the second on August 7. It was a dry hot summer, and while the yields were low, they still expressed a residual influence of the cutting treatments of 1931, 1932, and 1933. With alfalfa growing on soil of optimum fertility, early cutting of the first crop in 1932 and 1933 reduced the yields (Table 5) in 1934 by 0.6 ton, or 26.2%, in case of cutting treatment AA; 0.71 ton, or 35.8%, in case of treatment BB; and 0.61 ton, or 39.6%, for treatment CC as compared with the deferred cutting treatments A, B, and C. Similarly, with a moderately low level of fertility, the reductions in the yields from previous early cuttings of the first growth were 0.34 ton, or 22.2%, for treatment AA; 0.53 ton, or 43.3%, for treatment BB; and 0.41 ton, or 40.6%, for treatment CC as compared with the deferred cutting treatments A, B, and C. The residual losses in 1934 from early cutting of the first growth in 1932 and 1933 are in general much higher than the losses (from 13.5% to 34.0%) sustained from removals of fall growth in 1931, 1932, and 1933.

The residual productivity (Table 5) of alfalfa with all cutting treatments was much greater in tonnage and soil with optimum fertility as compared with soil moderately low in fertility. The increases in yields (Table 3) due to greater fertility, ranged from 0.33 to 0.76 ton per acre, or from 42.0% to 84.0%.

SURVIVAL

Beginning in the fall of 1931, randomized counts of the surviving alfalfa plants were made in each plat and the data obtained are condensed in Table 6. As measured by counts made in 1934, the best survival prevailed in plats of high fertility where alfalfa was given deferred summer cuttings without removal of the fall growth. The most serious thinning of stand prevailed where leafhopper damage resulting from early cutting of the first growth was combined with the depressing effects of fall growth removals and moderately low fertility. The number of plants per unit area is not a fair indication of thickness of growth or of yields since with high fertility, high reserves, winter cover, and the absence of leafhopper damage, the surviving plants were more vigorous and occupied much more space. An estimate of the

condition of the stand in August, 1934, is given in the last column of Table 6.

TABLE 6.—*The effect of fall cutting treatments and early cutting of the first crop on the survival of Canadian variegated alfalfa sown June 27, 1930.*

Cutting treatments	Number of plants per square foot									Estimated condition of stand Aug. 27 1934
	1931,	1932			1933			1934		
	Nov.	Apr.	May	Nov.	Apr.	July	Aug.	May	Aug.	
					Optimum Fertility					
A	27	25	14	7.8	8.5	7.0	7.5	4.6	3.8	Very good
AA	—	—	—	7.3	7.3	6.5	3.0	2.7	2.3	Good −
B	36	24	12	7.7	8.0	5.0	5.6	3.1	3.4	Very good
BB	—	—	—	7.8	7.7	6.0	3.3	2.6	2.5	Fairly good
C	32	17	10	7.3	8.0	3.5	3.2	2.1	1.7	Poor +
CC	—	—	—	7.3	5.0	3.0	1.6	1.1	1.2	Poor
					Moderately Low Fertility					
A	30	24	12	6.7	7.0	4.5	5.9	3.6	3.7	Good
AA	—	—	—	7.0	6.7	5.5	3.8	2.9	2.5	Fair +
B	35	16	7	5.0	5.7	3.5	3.9	2.5	1.8	Fair −
BB	—	—	—	5.3	5.3	4.0	1.9	0.8	1.0	Poor
C	34	12	6	3.3	4.0	2.1	3.1	1.6	1.6	Poor − −
CC	—	—	—	3.3	2.7	1.8	1.4	0.5	0.8	Very poor

SUMMARY OF RESULTS FROM EARLY AND DEFERRED CUTTINGS OF FIRST GROWTH OF ALFALFA

The summer productivity of alfalfa as measured by two cuttings was greatly reduced by early cutting of the first growth. Alfalfa cut when about one tenth of the blossoms had appeared compared with that cut 12 days later when it was fairly well blossomed reduced the yields from the first cutting in 1932 and 1933 from 6.4% to 38.3% with the greatest losses prevailing with alfalfa which had suffered winter injuries because of unfavorable fall cutting treatments.

Early cutting of the first growth reduced the productivity of both the first and second cuttings. The reductions in yields of the first growth are ascribed primarily to the removal of the photosynthetic area before the accumulations of dry weight became most rapid, and such losses were most severe where previous fall cuttings had induced winter injury which retarded and weakened growth the following spring. The losses in productivity of the second crop were very pronounced (38.8% to 65.1%) and they were due, primarily, to leaf-

hopper injury which was manifested by an intense yellowing and stunting of the young top growth in all plats where the first crop had been cut early.

With all cutting treatments whether favorable or unfavorable, the immediate and residual productivity of alfalfa was markedly increased with the optimum level of soil fertility when compared with a moderately low level of soil fertility.

Fall cutting treatments, particularly when they reduced both winter cover and autumnal food storage, greatly intensified the losses from early cutting of the first growth.

The factors which depressed the productivity of alfalfa also shortened the duration of the stands.

GENERAL SUMMARY

Alfalfa is very sensitive in its response to managerial treatment under the environmental conditions of southern Wisconsin. The total production of oven-dried, weed-free alfalfa hay during the 4-year period (1931–1934) of this trial varied from 13.29 tons to 5.98 tons per acre in accordance with management.

The productivity and duration of Canadian variegated alfalfa was compared under favorable conditions of management, including the maintenance of an optimum level of fertility, ample summer and fall storage of food reserves, abundant vegetative winter cover, and the absence of leafhopper damage, with the alternatives of moderately low fertility, early cutting of the first growth and leafhopper injury, reduced winter cover and reduced fall and summer storage of food reserves. The responses of alfalfa to various combinations of such favorable factors and unfavorable stresses were measured on the basis of productivity and survival. It was not possible to differentiate fully the degree to which each factor of management influenced the productivity or duration of the alfalfa, but their interactions could be quite clearly approximated.

Cutting treatments not only affected the immediate productivity of alfalfa but also subsequent productivity and survival. Such residual influences were very significant in this trial.

All fall cutting treatments proved harmful in this experiment, but late fall cutting after maximum food storage had occurred was definitely less detrimental with respect to productivity and survival than fall cuttings which not only reduced vegetative cover but also autumnal storage of reserve foods.

An optimum level of fertility greatly increased the productivity and duration of alfalfa when compared with that grown on soil moderately low in fertility. This held true whether the cutting treatments were favorable or unfavorable with respect to root storage, winter cover, and leafhopper damage.

Twelve days earlier cutting of the first growth in 1932 and 1933 greatly lowered the immediate and subsequent productivity and the survival of alfalfa. It depressed the productivity of the first growth, particularly, of alfalfa which had suffered winter injuries induced by previous fall cutting treatments. It resulted in very severe infestations

of leafhoppers, which caused heavy losses in the productivity of the second growth and such losses were most pronounced when alfalfa had undergone winter injury induced by previous fall cutting treatments.

The residual effects of the various cutting treatments applied to alfalfa in 1931, 1932, and 1933 were reflected, clearly and definitely, in the productivity of alfalfa in 1934.

REACTION OF F_3 PROGENIES OF AN ORO × TURKEY-FLORENCE CROSS TO TWO PHYSIOLOGIC RACES OF *TILLETIA TRITICI* AND ONE OF *T. LEVIS*[1]

O. A. VOGEL AND C. S. HOLTON[2]

A MAJOR problem in the wheat-improvement program of the Pacific Northwest is the production of bunt-resistant varieties suitable for commercial use. This problem would be relatively simple were it not for the continued appearance of previously unknown physiologic races of bunt.

Oro (C. I. 8220)[3] and Turkey-Florence (C. I. 10080) are highly resistant to the other known races but are very susceptible to races L-8 and T-11, respectively, and both are slightly susceptible to T-8.[4] A cross of these two varieties of wheat might be expected to produce some segregates resistant to all the races of bunt.

METHODS

The cross Oro×Turkey-Florence was made at the Arlington Experiment Farm, Arlington (near Washington, D. C.), Virginia, in 1932 and the F_2 plants were grown under irrigation at the Arizona Agricultural Experiment Station, Tuscon, Ariz., in 1934.

Seed of each of 168 F_2 plants was divided into three lots of 43 to 50 kernels, depending upon the number available. One lot was inoculated with L-8, one with T-11, and the third with T-8. Sufficient seed of 22 additional F_2 plants was available for inoculating with L-8, and 13 of these were also inoculated with T-11. The seeds were space-planted approximately 2 inches apart in 10-foot rows on October 18 and 19, 1934, at Pullman, Wash. One row of each parent was planted after each 10 rows of progeny. Plant selections from F_3 families were tested in 1936 for resistance to the three races individually and for resistance to a composite of 18 collections containing at least five additional races. Plant selections made from the F_4 families were tested in 1937 to the 19 races described by Rodenhiser and Holton.[5]

The percentage of bunt of each row was determined on the basis of plant counts according to the method described by Smith.[6]

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[1]Cooperative investigations of the Division of Cereal Crops and Diseases and the Agricultural Experiment Station, State College of Washington, Pullman, Wash. Published as Scientific Paper No. 338, College of Agriculture and Experiment Station, State College of Washington. Received for publication October 26, 1937.

[2]Assistant Agronomist and Associate Pathologist, respectively. Acknowledgment is made to Dr. E. F. Gaines, Cerealist, and Mr. A. M. Schlehuber, Research Assistant, State College of Washington, Pullman, Wash., for their suggestions and cooperation.

[3]C. I. refers to accession number of Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

[4]L-8, T-11, and T-8 are race numbers assigned by H. A. Rodenhiser and C. S. Holton in a paper entitled "Physiologic Races of *Tilletia tritici* and *T. levis*", Jour. Agr. Res., 55:483-496. 1937.

[5]See footnote 4.

[6]SMITH, W. K. Inheritance of reaction of wheat to physiologic forms of *Tilletia levis* and *T. tritici*. Jour. Agr. Res., 47:89-105. 1933.

TABLE 1.—*Infection percentages produced by each of three races of bunt and the average percentages produced by all three races on parents and F_3 lines of Oro×Turkey-Florence.*

Progeny No.	Physiologic race L-8	T-11	T-8	Av.	Progeny No.	Physiologic race L-8	T-11	T-8	Av.
1098	5.0	0.0	0.0	1.7	1129	31.0	31.0	16.0	26
1148	11.0	0.6	0.0	3.9	1201	41.0	25.0	13.0	26
1166	7.3	4.4	0.0	3.9	1094	78.0	0.5	3.3	27
1114	10.0	0.5	2.5	4.3	1104	79.0	0.5	0.0	27
1079	4.3	15.0	5.6	8.3	1115	37.0	18.0	26.0	27
1101	23.0	0.0	3.2	8.7	1200	3.6	59.0	17.0	27
1136	34.0	0.0	0.0	11.0	1162	48.0	22.0	14.0	28
1164	30.0	1.1	1.0	11.0	1016	53.0	19.0	16.0	29
1174	4.4	24.0	5.0	11.0	1022	50.0	21.0	15.0	29
1083	38.0	1.3	0.0	13.0	1047	70.0	5.0	11.0	29
1052	7.6	26.0	7.1	14.0	1076	81.0	1.3	3.8	29
1124	42.0	0.0	0.0	14.0	1111	35.0	34.0	18.0	29
1019	12.0	26.0	7.6	15.0	1187	53.0	22.0	13.0	29
1089	45.0	0.5	0.5	15.0	1009	44.0	27.0	19.0	30
1099	16.0	26.0	3.3	15.0	1018	49.0	19.0	23.0	30
1118	45.0	0.0	0.5	15.0	1054	3.2	78.0	9.0	30
1091	7.9	35.0	4.4	16.0	1092	37.0	30.0	22.0	30
1126	16.0	21.0	11.0	16.0	1179	33.0	39.0	19.0	30
1023	18.0	31.0	1.5	17.0	1039	42.0	30.0	20.0	31
1045	26.0	14.0	9.7	17.0	1058	0.6	83.0	8.8	31
1147	47.0	1.3	2.6	17.0	1142	64.0	19.0	9.5	31
1152	49.0	0.5	2.5	17.0	1003	52.0	20.0	23.0	32
1020	17.0	17.0	20.0	18.0	1062	58.0	18.0	21.0	32
1064	7.5	37.0	9.4	18.0	1140	58	23	19	33
1086	7.0	44.0	4.2	18.0	1008	41	39	23	34
1117	17.0	18.0	18.0	18.0	1134	59	23	20	34
1125	19.0	28.0	6.4	18.0	1196	13	72	18	34
1151	53.0	0.0	1.6	18.0	1135	64	16	24	35
1161	46.0	5.4	1.2	18.0	1158	58	22	25	35
1189	51.0	3.0	0.0	18.0	1044	16	47	44	36
1190	49.0	2.7	1.4	18.0	1030	35	52	25	37
1074	23.0	18.0	17.0	19.0	1149	53	33	26	37
1107	35.0	17.0	7.0	20.0	1163	74	15	21	37
1141	58.0	0.0	0.7	20.0	1177	74	13	23	37
1172	57.0	0.5	1.1	20.0	1199	52	35	23	37
1122	61.0	1.1	1.0	21.0	1035	66	23	26	38
1123	10.0	44.0	10.0	21.0	1056	55	38	21	38
1194	6.4	46.0	10.0	21.0	1106	69	15	31	38
1051	14.0	48.0	5.0	22	1154	30	41	42	38
1066	30.0	28.0	8.9	22	1155	56	42	17	38
1082	61.0	0.0	5.9	22	1138	47	39	31	39
1150	36.0	17.0	12.0	22	1159	66	24	27	39
1004	39.0	19.0	12.0	23	1057	51	35	33	40
1063	63.0	4.4	2.9	23	1065	69	35	15	40
1105	22.0	37.0	9.3	23	1078	63	24	32	40
1130	69.0	0.0	0.0	23	1116	58	37	26	40
1176	41.0	17.0	11.0	23	1119	52	38	31	40
1087	30.0	31.0	12.0	24	1014	46	37	40	41
1103	67.0	0.0	4.1	24	1095	70	26	28	41
1128	40.0	16.0	17.0	24	1137	63	29	31	41
1010	72.0	0.0	1.5	25	1139	26	70	27	41
1067	40.0	27.0	11.0	26	1173	64	33	28	42
1127	42.0	19.0	17.0	26	1183	53	32	41	42

TABLE 1.—*Continued.*

Progeny No.	Physiologic race			Av.	Progeny No.	Physiologic race			Av.
	L-8	T-11	T-8			L-8	T-11	T-8	
1186	68	41	17	42	1015	94	37	46	59
1034	17	86	26	43	1112	39	81	57	59
1100	77	18	34	43	1069	55	75	49	60
1182	75	23	32	43	1002	66	63	57	62
1026	63	36	33	44	1198	52.0	70.0	65	62
1038	65	27	39	44	1042	62.0	75.0	55	64
1110	36	57	39	44	1081	53.0	76.0	63	64
1167	28	62	42	44	1170	52.0	67.0	72	64
1171	56	35	41	44	1184	48.0	91.0	62	67
1197	65	29	37	44	1005	71.0	71.0	75	72
1053	69	31	35	45	1046	68.0	70.0	84	74
1075	25	83	26	45	1011	74.0	90.0	74	79
1165	46	37	51	45	1033	64.0	94.0	79	79
1029	60	47	30	46	1055	63.0	87.0	86	79
1070	79	31	28	46	1191	65.0	83.0	88	79
1059	27	84	30	47	1102	79.0	86.0	83	83
1040	83	28	32	48	1007	82.0	95.0	75	84
1188	77	36	32	48	1050	76.0	86.0	93	85
1153	75	36	37	49	1195	86.0	85.0	88	86
1185	70	38	38	49	1077	87.0	88.0	86	87
1031	36	63	50	50	1202	32.0	50.0		
1043	82	38	30	50	1203	61.0	34.0		
1093	28	86	36	50	1206	34.0	19.0		
1027	68	33	52	51	1207	56.0	66.0		
1071	37	66	49	51	1208	46.0	0.9		
1146	31	58	64	51	1209	4.7	0.0		
1028	84	34	39	52	1210	50.0	77.0		
1088	79	35	44	53	1211	53.0	35.0		
1090	86	24	49	53	1212	32.0	1.1		
1178	73	35	51	53	1213	41.0	0.6		
1006	52	58	55	55	1214	20.0	29.0		
1080	52	71	43	55	1215	44.0	35.0		
1068	55	76	36	56	1218	60.0	88.0		
1113	41	68	59	56	1219	64.0			
1131	72	32	64	56	1220	56.0			
1160	43	78	48	56	1221	19.0			
1017	55	58	59	57	1222	24.0			
1021	85	32	53	57	1223	54.0			
1032	81	40	51	57	1224	14.0			
1041	37	59	76	57	1225	77.0			
1143	42	72	60	58	1226	53.0			
1175	27	84	62	58	1227	1.3			

Parents	Row No.	Physiologic race			Av.	Parents	Row No.	Physiologic race			Av.
		L-8	T-11	T-8				L-8	T-11	T-8	
Oro	1145	69.0	0.0	5.7	25	Turkey-Florence	1000	3.2	50.0	12.0	22
Oro	1169	68.0	5.6	4.7	26	Turkey-Florence	1156	3.8	55.0	10.0	23
Oro	1109	72.0	5.8	3.0	27	Turkey-Florence	1180	7.9	55.0	11.0	25
Oro	1097	73.0	3.2	7.6	28	Turkey-Florence	1072	5.9	63.0	8.6	26
Oro	1025	76.0	2.3	9.7	29	Turkey-Florence	1120	2.9	64.0	11.0	26
Oro	1049	68.0	7.3	13.0	29	Turkey-Florence	1024	4.4	68.0	10.0	27

TABLE 1.—*Concluded.*

Parents	Row No.	Physiologic race L–8	T–11	T–8	Av.	Parents	Row No.	Physiologic race L–8	T–11	T–8	Av.
Oro	1073	73.0	5.4	10.0	26	Turkey-Florence	1036	6.9	63.0	12.0	27
Oro	1193	78.0	3.4	4.8	29	Turkey-Florence	1168	15.0	58.0	8.6	27
Oro	1133	79.0	4.3	7.1	30	Turkey-Florence	1048	6.8	65.0	18.0	30
Oro	1001	86.0	3.3	4.3	31	Turkey-Florence	1060	5.8	64.0	20.0	30
Oro	1061	78.0	4.0	10.0	31	Turkey-Florence	1096	7.2	73.0	8.9	30
Oro	1085	74.0	4.0	15.0	31	Turkey-Florence	1132	5.7	71.0	14.0	30
Oro	1181	74.0	4.8	15.0	31	Turkey-Florence	1108	5.8	78.0	10.0	31
Oro	1037	85.0	0.0	9.5	32	Turkey-Florence	1144	9.0	71.0	13.0	31
Oro	1157	85.0	6.3	12.0	34	Turkey-Florence	1012	13.0	74.0	10.0	32
Oro	1013	85.0	2.5	16.0	35	Turkey-Florence	1192	12.0	71.0	13.0	32
Oro	1121	85.0	11.0	8.1	35	Turkey-Florence	1084	10.0	81.0	8.1	33
Oro	1205	78.0	6.2	—	—	Turkey-Florence	1204	3.1	71.0		
Oro	1217	66.0	0.5	—	—	Turkey-Florence	1216	8.9	61.0		

EXPERIMENTAL RESULTS

The percentage of bunt produced by each of the three races and the average percentage on each parent and progeny are recorded in Table 1. The progenies inoculated with all three races are listed in the order of the average percentage of bunt and those inoculated with less than three races are listed in the order of the row numbers.

A satisfactory genetic analysis of the results has not been made because of the lack of data for generations other than F_3, and too few F_3 lines were tested in view of the number of factors that appear to be involved. The data, however, do show some results of special interest from the standpoint of breeding for resistance to races of bunt.

There were 8 of 190 F_3 progenies with less than 5% bunt when inoculated with L–8, 33 of 188 progenies with less than 5% when inoculated with T–11, and 33 of 168 progenies with less than 5% when inoculated with T–8. Of even more interest is the fact that 4 of 168 F_3 families averaged less than 5% bunt for the three races. Selections from progeny 1098 continued to be highly resistant in the F_4 in 1936. In 1937 selections from these were bunt-free to 18 individual races and produced from 3 to 23% of bunted heads with L–8. The bunted heads produced by L–8 were mostly of the partially bunted type which usually contain from one to five bunt balls per head and are usually found on late tillers.

There was no correlation between the percentage of smut produced by races L–8 and T–11 in the F_3 progenies ($r = 0.0281$, $P = 0.77$), and only a low correlation between races L–8 and T–8 ($r = 0.4242$, $P = 0.01$). There was, however, a rather high correlation ($r = 0.7477$, $P = 0.01$) between the smut produced by races T–11 and T–8.

From the standpoint of practical breeding the use of T–8 is not necessary because all progenies resistant to both L–8 and T–11 were equally resistant to T–8.

The results obtained have prompted a repetition of the study now in progress for a genetic analysis.

SUMMARY

The reaction of the F_3 progenies of Oro×Turkey-Florence to two races of *Tilletia tritici* and one of *T. levis* was studied. Oro is susceptible to the *T. levis* race L-8; Turkey-Florence is susceptible to the *T. tritici* race T-11; and both parents are slightly susceptible to the *T. tritici* race T-8.

The factors for resistance to all three races of bunt apparently have been combined in some progenies and those for susceptibility in other progenies. Selections from progeny 1098 continued to be very highly resistant to all three races of bunt as well as to a composite of other races in the F_4 and to all of the 19 individual races in the F_5 generation. Selections from this progeny also appear to possess many of the desirable agronomic characteristics of both parents.

ROOT STUDIES OF FOUR VARIETIES OF SPRING WHEAT[1]

V. C. HUBBARD[2]

GENERAL observations at various times have suggested that a knowledge of the root systems may do much to explain differences in drouth resistance and yield of varieties of spring wheat. Preliminary studies indicated the probable importance of hair roots (small, fibrous roots, not root hairs), and, accordingly, four varieties known to differ in productivity at Mandan and likewise presumably different in drouth resistance, were selected for detailed studies.

MATERIALS AND METHODS

The varieties were Ceres (C.I. 6900),[3] Reliance (C.I. 7370), Marquis (C.I. 3641), and Hope (C.I. 8178). Their average yields at Mandan for the 5-year period 1928 to 1934 are 15.3, 15.0, 12.5, and 11.2 bushels per acre, respectively. Ceres and Reliance, on the basis of general observations and relative yields, are quite generally assumed to be more drouth resistant than the others. Hope is known to be very susceptible to high temperatures during the heading and ripening period and presumably also to drouth. All four varieties ripen at approximately the same time, except Reliance which usually matures a day or two later than the others.

Studies were made in two different years, *viz.*, 1933 and 1934. In each case the plants for study were grown in duplicate in U-shaped frames 4 feet long, 4 inches wide, and 3 feet deep buried in the ground. In the first year the frames were covered with coarse, woven wire and in the second nail-studded, removable paneled sides were used. When the plants were mature the earth surrounding the frames was removed and the latter containing the plants were lifted from the ground to facilitate washing the soil from the roots.

Uniform stands were obtained by planting thick and thinning. The plants were spaced 3 inches apart in a row and there were 16 plants per frame, or a total of 32 plants of each variety. No water was applied or other attention given throughout the growing season other than to remove occasional weeds.

Random samples of roots for study were taken from the first, second, and third foot levels. No distinction was made between seminal and adventitious roots. The root samples were preserved in small vials in diluted alcohol and the number of fibrous roots arising from each 2-cm section were counted under a 6 × magnifying glass.

The diameters of the root sections of Hope and Ceres only were determined. This was done by photographing 20 representative sections of each, enlarged to 10 times natural size, and measuring with a Starret micrometer caliper accurate to 0.001 inch. The total air-dry weights of the 192 2-cm root sections of each variety were recorded as indicative of the relative size of roots.

EXPERIMENTAL RESULTS

The number of hair roots arising from each 2-cm section varied from 1 to 24, as many as 3 sometimes arising from a single point on

[1]Results of investigations conducted cooperatively by the Division of Cereal Crops and Diseases and the Division of Dry Land Agriculture, U. S. Dept. of Agriculture, at the Northern Great Plains Field Station, Mandan, N. Dak. Received for publication October 26, 1937.

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[3]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

the root. There were no observable varietal differences in the latter respect though there were differences in number and size. The average number of hair roots on each 2-cm section for each of three soil levels for the four varieties are given in Table 1 and the average diameters and air-dry weights in Table 2.

TABLE 1.—*Annual and average number of hair roots on 2-cm root sections in three soil levels of four varieties of spring wheat.*

Year	No. of root sections examined in each soil level	Average number of fibrous roots arising from 2-cm root sections at			
		1 to 12 in.	13 to 24 in.	25 to 36 in.	Av. 1 to 36 in.
		Ceres			
1933 .	90	7.9 ±.16	6.9 ±.12	8.0 ±.13	7.6 ±.08
1934 ...	192	11.2 ±.14	10.0 ±.12	11.2 ±.13	10.8 ±.08
Average		9.6 ±.11	8.5 ±.09	9.6 +.09	9.2 ±.06
		Reliance			
1933.	90	8.4 ±.14	6.2 ±.11	7.7 ±.14	7.4 ±.09
1934.	192	11.4 ±.16	10.0 ±.13	10.8 ±.16	10.7 ±.09
Average		9.9 ±.11	8.1 ±.09	9.3 ±.11	9.1 ±.06
		Marquis			
1933. .	90	9.0 ±.19	6.9 ±.12	7.6 ±.14	7.8 ±.09
1934...	192	9.5 ±.12	8.9 ±.13	9.3 ±.13	9.2 ±.07
Average		9.3 ±.11	7.9 ±.09	8.5 ±.09	8.5 ±.06
		Hope			
1933...	45	7.3 ±.17	7.0 ±.16	7.3 ±.17	7.2 ±.10
1934..	192	10.2 ±.15	10.0 ±.14	10.7 ±.16	10.3 ±.09
Average		8.8 ±.11	8.5 ±.08	9.0 ±.12	8.8 ± 06

The differences in numbers of hair or fibrous roots per unit section are small and not entirely consistent as between the different soil levels, but nevertheless appear to be greater than can be explained by random errors. On the average for all levels, Ceres has the largest number, Reliance the second largest, and Marquis the least. The difference between Ceres and Reliance may easily be due to random variation and the same may be said of the difference between Marquis and Hope.

In 1933 an estimate was made of the total number of hair roots per plant by determining the number of seminal roots that penetrated three or more feet of soil for each of 20 plants of each of the four varieties. These values, multiplied by the number of hair roots for each seminal root, may be regarded as an index of the total number of hair roots per plant. The indices so determined for each variety are 4,031, 3,891, 3,887, and 3,687 for Ceres, Reliance, Marquis, and Hope, respectively. The number of determinations are too few to permit a definite conclusion as to a relation between number of hair roots on

TABLE 2.—*Average diameter and weight of representative roots from three soil levels.*

Variety	Number of samples	Soil levels 1 to 12 in.	13 to 24 in.	25 to 36 in.	Average 1 to 36 in.
		Diameter of Roots, mm			
Ceres	20	0.231 ±0.003	0.209 ±0.001	0.196 ±0.001	0.212 ±0.001
Hope ..	20	0.258 ±0.001	0.251 ±0.001	0.177 ±0.001	0.229 ±0.001
Diff. Hope-Ceres..		0.027 ±0.003	0.042 ±0.001	0.019 ±0.001	0.017 ±0.001
		Weight of Roots, Grams per 192 2-cm Sections			
Ceres ..		0.0651	0.0402	0.0334	0.1387
Reliance		0.0351	0.0310	0.0224	0.0885
Marquis		0.0551	0.0500	0.0310	0.1361
Hope		0.0586	0.0327	0.0259	0.1172

the one hand and yield and drouth resistance on the other. However, the differences are such as would be expected if a relation of this kind exists.

On the average the roots of Ceres were smaller in diameter (Table 2) than those of Hope, but here again the differences are not entirely consistent for the different soil levels. Also, contrary to what would be expected, the weight of the roots per unit section was somewhat more for Ceres than for Hope. There seems little reason to expect a relation between yield or drouth resistance, on the one hand, and diameter or weight of roots, on the other, and little if any is indicated in this study.

SUMMARY AND CONCLUSIONS

The number of fibrous or hair roots per 2-cm section of the roots, and the weight per unit section of the roots of four varieties of spring wheat differing in yield at the Northern Great Plains Field Station, Mandan, N. Dak., and believed to differ in drouth resistance, were determined for different soil levels to a depth of 36 inches in 1933 and 1934. Diameter measurements of the roots of Ceres and Hope were taken at three soil levels. The number of seminal roots per plant penetrating to a depth of 3 feet or more was also determined which, multiplied by the number of hair roots per root, may be regarded as an index of the number of hair roots per plant.

Ceres and Reliance were found to have slightly more hair roots per unit section of root than Marquis and Hope and they likewise appeared to have a larger number of hair roots per plant. The differences were greater than can be explained by random errors, but nevertheless were not entirely consistent at different soil levels.

The data are regarded as indicative only of a relation between yield under conditions of drouth and numbers of hair roots per unit length of root and per plant. Differences in diameter and weight of roots per unit length were observed but little evidence was secured to indicate a relation between these differences and yield or drouth resistance.

A RESPONSE OF ALFALFA TO BORAX[1]

L. G. WILLIS AND J. R. PILAND[2]

ONE of the greatest difficulties experienced in developing a well-balanced system of agriculture in the southeastern states is associated with a soil peculiarity that has heretofore made it impractical to use lime except at limited rates of application.

For some time liming has been known to promote a deficiency of available manganese on extensive areas, but the soils involved are generally relatively high in residual organic matter because of poor natural drainage.[3] On the lighter sandy soils the characteristic symptoms of manganese deficiency have never been observed even with extremely heavy liming. Recently, a response to boron has been noted on several of the lighter soil types of the state where lime has been used liberally. Heavy applications of lime are also believed to promote a deficiency of potassium, particularly on sandy soils.

Contrary to all of the evidence indicative of adverse effects of heavy liming, one grower has succeeded for 15 years in producing alfalfa on a deep phase of Norfolk sand. Although the soil is extremely low in content of nutrient elements, no unusual fertilizer requirement has been evident. One outstanding peculiarity has been an apparently abnormal requirement for lime. With a weakly buffered soil, having a pH value well above 7.0 from prior liming, it has been necessary in many cases to apply ground limestone at rates up to 5 tons or more to the acre to insure a satisfactory stand with each new planting. While no formal experimental evidence has been obtained to demonstrate this need for lime, it has been observed that fields which have failed, supposedly from too light an application, have produced satisfactory growth where lime has been spilled in unloading from trucks to the distributor.

The grade of lime used was a ground dolomite by-product from a mining industry which contained appreciable amounts of heavy metallic elements such as copper, manganese, and zinc.

NEGATIVE EFFECT OF MINOR CONSTITUENTS OF LIMESTONE

The possibility that the apparent response to lime was actually due to an effect of these elements was tested experimentally on a field where a recent planting of alfalfa was failing presumably because too small an application of lime had been made. Amounts of copper, manganese, and zinc sulfates equivalent to the content of these elements in 10 tons of the grade of limestone used were applied to

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, State College Station, Raleigh, N. C. Published by consent of the Director of the Agricultural Experiment Station as No. 102 of the Journal Series. Also presented before the Division of Fertilizer Chemistry at the ninety-fourth meeting of the American Chemical Society in Rochester, N. Y., Sept. 7, 1937. Received for publication October 27, 1937.

[2]Soil Chemist and Assistant Soil Chemist, respectively.

[3]WILLIS, L. G. Response of oats and soybeans to manganese on some Coastal Plain soils. N. C. Agr. Exp. Sta. Bul. 257. 1928.

plats in the field. These treatments were placed late in the spring. No effects were noted during the summer and the tests were discontinued.

A few years later the alfalfa began to die on a number of fields regardless of the amount of lime used or the pH of the soil. In appearance, the affected plants resembled those that had previously failed because of an insufficient application of lime. In the latter cases none of the ordinary fertilizer materials had been beneficial.

RESPONSE TO BORAX

The possibility of a boron deficiency was introduced by evidence from other experiments of a response to borax, particularly with truck crops on liberally limed soils.[4] Reconnaissance tests with varying amounts of borax placed at random on affected alfalfa fields in early March gave evidence of distinctly beneficial effects from applications of 5 pounds to the acre. The most striking differences were noted during midsummer.

Plants showing the symptoms that were corrected by borax were typically yellow in the terminal growth. Frequently the apical buds were dead and blossoming retarded. Severe wilting occurred during hot dry weather and the plants seemed to be abnormally infested with aphids or leaf hoppers.

SUPPLEMENTARY FIELD AND POT EXPERIMENTS

In the results of the preliminary tests there appeared to be sufficient justification for a conclusion that the problem involved only a boron deficiency. There remained, however, the question of the apparent need for excessive quantities of lime and the successful production of alfalfa for years on the land. Following the tests with borax alone, therefore, another more comprehensive experiment was placed on a field where the yellow condition was moderately severe. This consisted of copper, manganese, and zinc sulfates and borax at rates of 5, 10, 10, and 5 pounds, respectively, to the acre, each material being applied to 1/100-acre plats separately and in all possible combinations. In addition, applications of borax were made at rates of 10 and 20 pounds to the acre.

This detail of the experimental work was started in the field late in May and at the same time soil from another field where alfalfa had failed completely was taken to the greenhouse for additional experimentation.

In the field no effects were visible during the year in which the treatments were applied. The soil taken to the greenhouse was put into 1-gallon glazed earthenware pots late in May and alfalfa was seeded. The treatments applied were copper, manganese, and zinc sulfates separately at the rates used in the field and each with borax at a rate of 10 pounds to the acre. No distinct response was noted except from the borax, although there was slight evidence of the occurrence of a parasitic disease on the plants receiving the copper sulfate alone.

The plants grown in the pots developed the typical yellow color in the terminal leaves, sometimes tending toward a red (Fig. 1). The

[4]WILLIS, L. G., and PILAND, J. R. Some observations on the use of minor elements in North Carolina agriculture. Soil Science, 44:251–263. 1937.

internodes were short and branches developed at the nodes. Late in September, however, the plants grown without borax improved in appearance and within a few weeks became equal in all respects to those to which borax had been supplied.

This, together with the observation made in the field that the abnormal condition of alfalfa occurred only between late spring and midsummer, suggested the possibility of a relation to photoperiodism. An attempt to verify this possibility experimentally has not been successful, but it suggested an explanation for the failure of borax to produce a beneficial effect when applied late in the season to an old planting.

FIG. 1.—Characteristics of alfalfa grown in pots on "yellows" soil. (1) With borax; (2) without borax.

The field experiment with copper, manganese, zinc, and borax was therefore continued without modification through the second year. In May it was noted that the entire field had developed the yellow color with the exception of some of the treated plats. No attempt was made to harvest these for record as the stand had been reduced unevently before the treatments had been applied. The plats were classified, however, on the basis of color and relative growth into two groups. In the group designated as A very few or no yellow leaves appeared and the plants were fully twice the height of those in the remainder of the field. Group B contained plants that were predominantly yellow and little or no better than those in the field.

According to this classification the effect of treatment was as follows:

Effect of Metallic Elements and Borax on Yellow Alfalfa

Group A, normal plants	Group B, defective plants
B	Mn
B Mn	Cu
B Cu Mn	Zn
B Cu Mn Zn	B Cu
B Mn Zn	B Zn
B Cu Zn	Cu Zn
Cu Mn Zn	Mn Zn

There are three outstanding items to be noted. Borax was distinctly beneficial (Fig. 2) except where it was combined with copper or zinc. Manganese corrected this adverse effect of copper or zinc when used with borax and the combination of copper, manganese, and zinc was as effective as the treatments containing boron. The plats receiving 10 and 20 pounds of borax were approximately equal to those receiving 5 pounds.

FIG. 2.—Left foreground, field response to 5 lbs. of borax to the acre in the second year.

Reverting then to the earlier attempt to demonstrate this effect of the metallic elements, a suggestion is made that the treatments were applied too late in the season to produce a response and that beneficial results might have been noted the following year if the work had been continued. Until further information is available, however, the cause of the abnormal condition of the alfalfa cannot be stated. For practical usage it can be considered a boron deficiency and the simplest and most economical remedy will be borax applied at a rate of 5 to 10 pounds to the acre where the soil is distinctly basic.

EXTENT OF THE BORON PROBLEM

At the outset this problem was thought to be confined to the sandy soils. Since the final results have been obtained, however, specimens of alfalfa plants have been received from various parts of the state where the same symptoms of injury have been noted. The soils range from sandy loams to heavy clays. If the causal factors in the latter cases are different from those found in the experiments they cannot be distinguished by plant symptoms. Should there be several distinct

causes of the yellow condition it is probable that the one which is remedied by boron can best be identified by the characteristic increase in severity in early summer and recovery later.

The problem of insect infestation in relation to the boron effect has not been studied systematically. On one field which showed the yellowed condition late in March, aphids were extremely abundant and leafhoppers were either absent or scarce. An alfalfa seeding failed completely in strips through another field where the intended application of manure was missed. Soil from one of these strips was taken to the greenhouse where it was used in a pot experiment. An occasional white fly and aphid was seen on the plants but not in sufficient numbers to have caused any abnormalities. It was in this series of pots that the response to boron already referred to was obtained. Apparently insect infestation is not the primary cause of alfalfa yellows although it may be a contributing factor.

Apparently this condition in alfalfa is extremely common[5] and there is a strong probability that it may be aggravated by the use of fertilizers containing soluble calcium salts since reports indicate that it is very prevalent where superphosphate has been used liberally, and early work[6] has shown that calcium sulfate increases the severity of boron deficiency symptoms.

SUMMARY

The yellowed condition of alfalfa which occurred on some soils in midsummer has been corrected by additions of borax. Manganese appears to supplement the effect of borax. Zinc and copper have antagonistic or negative effects, but a combination of manganese, zinc, and copper sulfates produced results similar to those obtained with borax. Borax effectively corrected the abnormal condition when applied in March, but failed when applied late in May of the same year. Tentatively, it is suggested that there is a photoperiodic factor involved.

The yellow condition is general on all alfalfa soils within North Carolina. It seems to be aggravated by liming and by the liberal use of fertilizers high in soluble calcium salts.

Abnormal infestation by sucking orders of insects seems to be associated with the condition of plants which is remedied by borax.

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[5]Since this manuscript was prepared, our attention has been called to a report of what is probably an identical condition, described in a paper entitled, "A Yellowing of Alfalfa Due to Boron Deficiency", Sci. Agr., 17:515-517. 1937.

[6]See footnote 4.

THE TRANSGRESSIVE INHERITANCE OF REACTION TO FLAG SMUT, EARLINESS OF HEADING, PARTIAL STERILITY, AND STIFFNESS OF GLUMES IN A VARIETAL CROSS OF WHEAT[1]

T. H. SHEN, S. E. TAI, AND S. C. CHANG[2]

THIS paper reports a case of transgressive inheritance of several characters in a varietal cross. The study was carried from F_1 to F_5 of a cross between a Chinese variety, Pathology 4592, and an Australian variety, Nebawa. The two parents were practically immune to flag smut, *Urocystis tritici* Koern., at Nanking. They were also medium early, easy in thrashing, and fully fertile. In F_2, F_3, F_4, and F_5 of the cross there were some plants susceptible to flag smut, some heading earlier than either parent, some partially sterile, and some having stiff glumes.

MATERIALS AND METHODS

The parental variety, Pathology 4592, was selected from a farmer's variety at Wei-hsien, Shantung, and Nebawa was obtained directly from Australia. These two varieties were tested by the Pathology Division of the University of Nanking for their reaction to flag smut in 1926–1933, inclusive. They were free from smut infection throughout the nursery tests. A half mou (about 1/12 acre) of each was grown in 1933 in addition to the nursery tests. No smut was found in the plat of 4592, although two smutted plants were found in Nebawa. The former, therefore, can be considered as immune and the latter as nearly immune to the biological strains of flag smut found at Nanking. However, both varieties showed a small percentage of flag smut in the tests in Honan and Shensi.

The methods of smut inoculation used previously by the Division of Plant Pathology of the University of Nanking were followed. The fungous spores were supplied every year by the Pathology Division. It was stated that the smut was collected originally from a farmer's field in Nanking in 1925. The spores supplied for this study originated from a single row harvested in 1927 in the hope of having one biological form. For inoculation each envelope containing wheat grains and smut spores was emptied into a brass dipper, 6 cm in diameter, with holes in the bottom. The dipper was then shaken vigorously to insure distribution of the spores on the grain.

In taking notes on smut reaction in this study, the percentage of infection was based on the number of infected plants. In the F_3 progenies, notes were taken on both plant and culm infection for comparison.

The date of heading was taken for each plant as the tip of the first head emerged from the auricle of the top leaf.

The hybrids were first made in the spring of 1932. In order to obtain adequate data on date of heading in F_1 and to increase the size of the population in F_2, further crosses were made in the spring of 1934 and that of 1936. The F_1 plants were grown together with the parents in the greenhouse prior to 1937, but in 1937

[1]Joint contribution from the Department of Agronomy of the University of Nanking and the Wheat Section of the National Rice and Wheat Improvement Institute, Nanking, China. Received for publication October 28, 1937.

[2]Professor of Plant Breeding and Chief Technician, Senior Agronomist, and Research Assistant, respectively.

the F_1 plants were grown with the parents in the plant breeding garden of the University of Nanking to obtain notes on date of heading under field conditions. The F_2, F_3, and F_4 plants were also grown with the parents in the garden. In the field, seeds were sown 3 inches apart in 5-foot rows which were spaced a foot apart. All seeds of the parents and of the F_1, F_2, F_3, and F_4 for planting were heavily inoculated with smut spores and then sown in the garden where the study had been carried on during the three previous years. The planting was done about October 20 at which time the temperature was about 60° F. Pathology 1102, a very susceptible variety, was sown around the bed as a guard and as a means of obtaining an available supply of smut spores.

Cytological studies were made on the sterile F_5 plants by using the modified iron acetocarmine smear method described by McClintock.[3]

INHERITANCE OF REACTION OF FLAG SMUT

The cross of Pathology 4592 and Nebawa was made to learn whether or not these two varieties have the same genotypes with regard to immunity to flag smut. There were 19 hybrid seeds in 1934 and 109 hybrid seeds in 1936, which were heavily inoculated and sown in the greenhouse and in the garden, respectively. All of the F_1 plants grown either in the greenhouse or field were entirely free from smut. Out of 394 F_2 plants grown in the field in 1933–34, 2 plants were partially smutted, i.e., 6 of 12 culms in one plant and 2 of 11 culms in the other being smutted. In another F_2 generation which was grown in 1935–36, 19 out of 1,514 plants were partially smutted. Considered on a percentage basis, the former F_2 gave 0.51% of smut and the latter 1.25%.

In F_3, 345 progenies from the 394 F_2 plants were raised and 80 of them showed a low degree of smut infection. The frequency distribution of the F_3 families with respect to the percentage of flag smut is shown in Table 1. There were two families with the percentage of smut above 10, i.e., one family having 5 smutted out of 54 plants and the other 4 smutted out of 32 plants. The total number of plants grown in F_3 was 24,567 and 143 of them showed smut, giving 0.58% smut.

TABLE 1.—*The frequency distribution of F_3 families with respect to the percentage of flag smut in 1935.*

Classes for smut percentage	0	0.5–2.49	2.5–4.49	4.5–6.49	6.5–8.49	8.5–10.49	10.5–12.49	12.5–14.49	Total
No. of F_3 families	265	49	18	7	1	3	1	1	345

Progenies of the two F_2 smutted plants of the 1933–34 crop were grown in F_3, and one of them did not show any smut, while the other gave 0.97% infection. Neither of these F_2 plants seems to be very susceptible, as one F_3 progeny was free from smut and the other showed only a trace of smut.

[3]McCLINTOCK, B. A method for making acetocarmine smears permanent. Stain Tech., 4:53–56. 1929.

In order to know whether the lines are as susceptible as either Nanking 1102, which has been considered the most susceptible variety, or Nanking 26, which has been considered to be of medium susceptibility, progenies were grown from the 19 F_2 susceptible plants of the 1936 crop and the 21 F_3 susceptible plants of the 1935 crop, respectively, together with 1102, 26, and the parents. The results are presented in Table 2. Several lines did not show any smut, but some lines did show an even higher percentage of smut than Nanking 1102 and 26. This leads to the conclusion that lines as susceptible as Nanking 1102 and 26 were isolated.

TABLE 2.—*The frequency distribution of F_3 and F_4 families from the susceptible parents with respect to the percentage of flag smut in 1937.*

No. of families	0	0.5–3.9	4.0–7.9	8.0–11.9	12–15.9	16–19.9	20–23.9	24–27.9	28–31.9	Total
F_3	12		5			1		1		19
F_4	8	3	5	4	1				1	21
Nanking 26				1						
Nanking 1102							1			
Nanking 4592	1									
Nebawa	1									

The percentage of infection in F_3 for those families that showed some smut infection was based on the percentage of culms smutted and the percentage of smutted plants. The plant basis gives a higher percentage of infection than the culm basis. The coefficient of correlation between these two is $r = 0.676 \pm 0.061$ which is highly significant. The plant basis has been used because it is somewhat easier to determine.

Immunity to flag smut is a dominant character and segregation occurs in F_2. The factors responsible for immunity in the two varieties Pathology 4592 and Nebawa are not alike. The susceptible plants in F_2 and the susceptible families in F_3 and F_4 were due to the combination of the recessive genes for susceptibility from the two parents. Some lines from the cross between Nebawa and Pathology 4592 were as susceptible as the medium or the most susceptible varieties, such as Nanking 26 and 1102. The genes for flag smut reaction seem to be multiple in nature.

INHERITANCE OF EARLINESS

There were 109 F_1 plants, 95 plants of Pathology 4592, and 81 plants of Nebawa grown in 1936–37 in the garden. The date of heading of F_1 plants covered practically the whole range of the two parents with a mean close to the early parent. The F_2 population both in 1934 and 1936 was much larger than that of the parents, as shown in Table

3. In both years a number of F_2 plants headed earlier than the early parent, but no plants headed later than the late parent. The F_3 data gave more evidence regarding segregation.

TABLE 3.—*Frequency distribution for date of heading of F_1 and F_2 generations and their parents under field conditions.*

Generation	Date of heading in class interval*											Total	Mean±S. D.
	1	2	3	4	5	6	7	8	9	10	11		
							1934						
P_1A†			5	15	2							22	10.773±1.412
P_1B†				12	21	7	1					41	14.073±2.065
F_2	12	51	117	93	51	19	2					345	9.583±3.566
							1936						
P_1A		13	28	31	4							76	9.026±2.460
P_1B						3	24	28	7	1	2	65	22.307±2.919
F_2	13	112	301	512	356	180	36	3	1			1,514	11.549±3.687
							1937						
P_1A	21	28	12	26	6	1	1					95	7.21±4.13
P_1B			2	5	9	30	21	10	4			81	18.04±3.86
F_1	2	2	25	36	28	13	2	1				109	11.80±3.60

*Size of class interval is 3. Class interval 1 means April 21, 22, and 23 in 1934; April 22, 23, and 24 in 1936; and April 20, 21, and 22 in 1937.
†P_1A = Pathology 4592, and P_1B = Nebawa.

The mean and S. D. for date of heading were calculated for each F_3 line. The calculated means for the parents, Pathology 4592 and Nebawa, which were grown in the same field with the F_3 in 1935, were 14.195±2.202 and 25.769±2.058, respectively. Three F_3 lines with means of 8.051±2.310, 9.218±2.244, and 11.075±2.781, respectively, headed apparently earlier than the early parent and were also relatively homozygous. Two lines averaged to head on 27.191±3.570 and 28.238±3.105 which is slightly later than the late parent, but their S. D.'s are larger than the late parent. There is some evidence that, although no homozygous lines are significantly later than the late parent, some plants in these two and possibly other lines are genotypically slightly later in heading than the late parent.

The coefficient of correlation between the date of heading and S. D. of the F_3 lines as shown in Table 4 is $r = -.347$ which leads to Fisher's $Z = .337$ and its S. E. $= .125$. The correlation is significantly negative, and although not very large, it indicates that families of late heading with small S. D. are proportionally greater than those of early heading. This relation suggests a partial dominance of early genes over late genes.

The number of genes involved in this cross can not be determined with certainty; but as the mean date of heading of F_1 plants was close to the early parent, the extremely early and late families as well as the parental types appeared in F_2 and F_3, and relatively homozygous families of F_3 in each class group were indicated with small standard deviation, the genes involved are multiple, the early genes are par-

TABLE 4.—*Classifications of F_3 families on the basis of mean date of heading and standard deviation.*

S. D. (Y)	Mean for date of heading (X)							Total
	7.5–10.49	10.5–13.49	13.5–16.49	16.5–19.49	19.5–22.49	22.5–25.49	25.5–28.49	
1.4–2.09						3		3
2.1–2.79	2	1	2	1	1	4	2	13
2.8–3.49	4	1	1	2	2	2	1	13
3.5–4.19	1	4	5	1	5		1	17
4.2–4.89		5	3	2				10
4.9–5.59		1	5	2	1			9
5.6–6.29		1	1					2
Total	7	13	17	8	9	9	4	67

$r = -.347$ $Z = -.337 \pm .125$

tially dominant over the late genes, and the effect of the genes is rather minute.

It was questioned whether the mean, median, or modal date of heading of F_3 lines was best correlated with the date of heading of the F_2 plants. The coefficient of correlation between them, Fisher's Z, and the differences between Z values were calculated and shown in Table 5. All of the coefficients and Z values were very high, showing that either mean, median, or modal date of heading of F_3 lines can be used with relative reliability. On the basis of differences between Z values, the correlation between date of heading in F_2 and the median date in F_3 is significantly greater than the correlation between F_2 with either mean, or mode.

TABLE 5.—*Correlating the mean, median, and modal date of heading of the F_3 lines with the date of heading of the F_2 plants.*

Correlation on basis of	r	Z	Z differences
(1) Median	0.964	2.000	(1)–(2) = 0.466 ± 0.177
(2) Mean	0.911	1.534	(1)–(3) = 0.633 ± 0.177
(3) Mode	0.866	1.317	(2)–(3) = 0.217 ± 0.177

STIFFNESS OF GLUMES

Stiffness of glume was studied by pulling the outer glumes in the middle and top part of the spikelets because those of the base spikelets are usually fairly stiff. The glumes of both parents are not stiff at all. The glumes of F_1 plants were not stiff, but in F_2 there were 312 plants showing normal and 33 plants which were fairly hard to thrash. Their degree of stiffness was not so high as Nilsson-Ehle's speltoid type A, B, or C. Out of the 33 F_2 plants that were hard to thrash, the progenies of 16 were tested in F_3. Three families bred true for stiffness of glumes, the others showed segregation, and one family failed to show stiffness, indicating the possibility of a wrong classification in F_2. In addition to the 15 families, the progenies of 105 F_2 plants that were easily thrashed were tested in F_3, and 72 progenies segregated from

1% to 55% of plants with stiff glumes. In total, 87 out of 121 progenies tested gave some plants with stiff glumes. The mode of inheritance is rather complicated.

PARTIAL STERILITY

Both parents were fully fertile. Both Nebawa and Pathology 4592 produced three seeds per spikelet, the latter occasionally giving four seeds per spikelet with three-seed spikelet as a standard. The F_1 appeared to be completely fertile. Out of 394 plants in F_2, 3 plants, 288a1–39, 288a1–94, and 288a1–102, were found to be partially sterile. Progenies from two of these plants were tested in F_3. The family 288a1–39 gave three plants out of a total of eight with 20%, 25%, and 35% of sterility, respectively. The family 288a1–94 gave 6 plants out of a total of 17 with 20%, 25%, 30%, 30%, 70%, and 75% of sterility, respectively. A few other families in F_3 also gave partially sterile plants. Data from these families are given in Table 6. Out of a total of 67 F_3 lines grown from F_2 plants that were fertile, 12 lines gave some plants that were partially sterile as shown in Table 6.

TABLE 6.—*Frequency distribution of sterile plants in F_3 lines that gave some sterile plants.*

Family No.	Total No. of plants	No. of sterile plants	Percentage sterility of F_3 lines				
			1–20.9	21–40.9	41–60.9	61–80.9	81–100.9
288a1– 4	19	1		1			
39	8	3	1	2			
–54	70	2	1	1			
–79	49	15	2	6	3	4	
–94	17	6	1	3		2	
a3– 8	62	1			1		
–27	69	1	1				
–28	69	17	1	7	7		2
a4– 7	59	5	2	2			1
–17	55	2		1			1
–20	83	1				1	
–22	70	3		3			
–31	79	5	3	2			
–32	73	4	1	1			2

The progenies of 12 F_3 plants with 52.2% to 98.6% sterility were grown in the greenhouse. The three F_3 plants with 92% to 99% sterility produced only one to five poorly developed seeds which failed to germinate. Another F_3 plant with 83% of sterility produced only two F_4 plants with 22% and 50% sterility, respectively. The eight other lines gave 21% to 34% of mean sterility as shown in Table 7.

In order to find out the cytological behavior of those sterile plants, a study was made on the sterile F_5 plants. Microsporocytes of these plants were examined. The results tabulated in Table 8 indicate clearly that the sterile plants arose through some sort of chromosomal aberration. Their somatic chromosome numbers are all below

TABLE 7.—*Sterility in F_4 lines.*

Line number	Percentage sterility of F_3 plants	Total number of plants in F_4	Mean percentage of sterility ±S. E. in F_4
a1-79-43	52	30	21.0±3.7
a1-94-2	65	39	27.9±4.3
a1-94-11	70	22	29.5±3.3
a1-79-47	79	14	25.0±6.6
a1-79-20	80	17	20.9±4.6
a1-79-44	84	59	33.6±3.6
a1-79-46	84	4	18.0±1.6
a1-94-5	85	17	33.2±4.9

the normal hexaploid (42) and range from 30 to 35. The observed chromosome conjugations are rather variable, ranging from univalents to tetravalents. The lowest number of bivalents is 13 and the highest 16, and both 14 and 16 were most frequently observed. The number of univalents ranges from 0 to 5 and from 0 to 4 at the first and the second metaphase stages, respectively, and the number of lagging chromosomes was found to be from 0-4 and from 0-6 during the first and the second anaphase stages, respectively. Spore quartets with extra small nuclei were frequently observed, ranging from 5.5% to 32.6% of the cells studied. Aborted pollen grains were also found, the lowest percentage being 1.3 and the highest 38.5. These variations seem to have their origin in the variation of somatic chromosome numbers, hence in the variation of chromosome conjugations.

Plants with 21 pairs of chromosomes were frequently observed. They were fully fertile and normal, just as their parents. Evidently the sterile plants have been constantly throwing out normal hexaploid plants. But those F_5 plants with 30 to 35 somatic chromosomes (showing less than 7 univalents in their chromosome conjugation) will be unable to give rise to progenies with 42 somatic chromosomes, because so far as the observed chromosome conjugations are concerned, there is no way for them to form gametes with 21 chromosomes, even figured on the basis that all bivalents behave normally and all univalents go to the same pole during anaphase. It may be predicted upon this basis that there would be no plants in the next generation possessing 42 somatic chromosomes.

As to the exact origin of the chromosomal aberration, it is not certain. Similar partial sterility has been frequently observed by L. Y. Shen and the writers in Chinese-foreign wheat varietal crosses. Furthermore, wheat has been grown in China for over 4,000 years, which is far longer than foreign wheats, especially those of American, Australian, and European origin, hence the chromosomes of the Chinese wheats may be more differentiated than those of the foreign wheats. More intensive study will be made in those Chinese-foreign wheat varietal crosses in which partial sterility has been observed in order to ascertain the cause of the chromosomal aberration. If the F_1 plants and the first sterile F_2 plants were studied cytologically, the cause of the chromosomal aberration in this cross might be understood more fully. At any rate, the occurrence of those sterile plants

TABLE 8.—*Showing the cytological results in the partially sterile F_5 lines of the cross Pathology 4592×Nebawa, 1937.*

F_4 families	No. of univalents		No. of lagging chromosomes		Spore quartets with extra small nuclei, %	Aborted pollen grains, %	Chromosome conjugation†
	IM*	IIM*	IA*	IIA*			
a1-79-20-7	0-1	—	1	—	0	—	$16_{II}+1_{I}$; 21_{II}.
a1-79-20-10	0	—	0	—	0	0	21_{II}.
a1-79-43-10	0-1	—	—	—	0	1.3	21_{II}.
a1-79-43-25	0-3	—	0-3	0-1	22.0	12.8	$16_{II}+1_{I}$; $16_{II}+3_{I}$; 21_{II}.
a1-79-44-8	0	0	0	0	0	0	21_{II}.
a1-79-44-29	0-4	—	0-4	—	11.1	11.2	$14_{II}+4_{I}$.
a1-79-44-47	0-5	—	—	0-2	0	10.2	$13_{II}+4_{I}$; $14_{II}+5_{I}$.
a1-79-44-53	0-2	—	—	0-2	18.7	—	$16_{II}+2_{I}$; 21_{II}.
a1-79-44-59	1	—	—	—	6.7	—	—
a1-79-46-2	0-5	—	—	—	—	—	—
a1-79-47-4	0-1	—	0-1	—	—	0	21_{II}.
a1-94-2-1	1	—	—	—	—	—	—
a1-94-2-3	0-3	—	—	0-2	16.7	—	$1_{III}+13_{II}+3_{I}$; 21_{II}
a1-94-2-4	0-3	0-4	0-4	0-6	32.3	38.5	$1_{IV}+14_{II}$; $16_{II}+1_{I}$
a1-94-2-11	0-3	—	—	—	17.6	31.9	—
a1-94-2-15	0	0	—	—	0	0	21_{II}.
a1-94-2-23	0-3	—	0-2	0-1	32.2	7.1	—
a1-94-2-37	0	—	—	—	0	—	21_{II}.
a1-94-5-11	0-2	—	0-2	0-1	20.7	11.3	$1_{III}+14_{II}+2_{I}$; $1_{IV}+14_{II}+1_{I}$; 21_{II}.
a1-94-11-3	0-2	—	0-1	0-2	5.5	—	—
a1-94-11-13	0	0	0	0	0	0	21_{II}.
Pathology 4592	0	—	0	0	0	0	21_{II}.
Nebawa	0	—	0	—	0	0	21_{II}.

*IM and IIM stand for first and second metaphase stages, respectively. IA and IIA stand for first and second anaphase stages, respectively.

†I stands for univalent, II for bivalent, III for trivalent, etc. Four or five F_5 plants were studied in each line and about five successful smears were used for each plant. The result represents a summary study of plants in each line.

from F_2 through F_5 generations is due to chromosomal aberration, just as suggested before the cytological study was made.

INHERITANCE OF AWNS, SHAPE OF BEAK, AND COLOR OF KERNEL

Pathology 4592 is bearded, while Nebawa has a few apical short awns. The F_1 was semi-bearded. There were 259 plants in F_2 that were either beardless or semi-bearded and 83 bearded plants, fitting a 3:1 ratio with partial dominance of beardless as usual. The bearded plants bred true in F_3, but the progeny of semi-bearded showed segregation. The apically awned plants bred true.

The shape of beak was also studied. Pathology 4592 is bearded with pointed beak and Nebawa is beardless with blunt beak. F_1 is semi-bearded with blunt beak. The inheritance of these two characters in F_2 is shown in Table 9. There were 250 plants with blunt beaks and 94 plants with pointed beaks, fitting a 3:1 ratio.

TABLE 9.—*Inheritance of awnedness and shape of beak in F_2*

Family No.	Beardless, blunt beak	Beardless, pointed beak	Bearded, blunt beak	Bearded, pointed beak
288a1	74	4	0	27
a2	54	4	0	16
a3	27	3	0	7
a4	29	0	0	6
a5	67	1	0	26
Total	250	12	0	82

The F_3 data proved pointed beak breeding true, while some of the blunt beak F_2 plants segregated for blunt and pointed beaks in F_3. The very close association between pointed beak and presence of awn and blunt beak and absence of awn took place in F_3.

Out of 12 beardless and pointed beak plants, 6 plants were tested further in F_3. The result is given in Table 10. They segregated into bearded and beardless. The beaks of the beardless plants were not as pointed as those of the bearded ones and not as blunt as those of the beardless plants in the other families. Some of the beardless plants should be heterozygous and should have intermediate pointed beaks. The remainder of the beardless plants should be homozygous and blunt in beak if these characters are assumed as due to the same genes.

TABLE 10.—*The genetic behavior of F_3 progeny of some beardless pointed beak F_2 plants.*

Family No.	Beardless, pointed beak	Bearded, pointed beak
288a1-11	38	21
-46	16	9
-73	28	12
a3-12	43	11
-22	38	13
-36	45	15

The color of kernel is another difference between the two parents. Nebawa has white kernels and Pathology 4592 has red ones. The F_1 kernel color was intermediate red, while in F_2 there were 339 red-kernelled plants and 6 white. The F_2 plants with white kernels bred true in F_3 and some of the red ones bred true while others gave segregation. Thus it is concluded that the color of kernel in this case is due to three pairs of genes.

RELATIONSHIP OF THE CHARACTERS STUDIED

It is of interest to see whether there is a linkage relationship between the characters studied. As there were only two plants in F_2 showing smut, the relationship between the reaction to smut and the date of heading was studied in F_3. The frequency distribution of the median dates of heading in the smut-free and the smutted families are compared in Table 11, $X^2 = .0484$ and P greater than .99, showing no significant difference between these two distributions.

TABLE 11.—*Probability showing whether the smut damaged and smut-free distributions with regard to the date of heading in F_3 are random samples of the same population.*

Median date of heading of F_3 families	5–10.99	11–16.99	17–22.99	23–28.99	Total	Chances
Smutted (1)	7	15	8	3	33	.2308
Free (2)...	22	51	26	11	110	.7692

As there are only a few smutted plants in the so-called "smutted families" in F_3, the comparison between the average dates of heading of the smutted and the smut free plants in the same family is not entirely reliable. There seems to be no consistent difference between date of heading of the smutted and smut-free plants in the same F_3 lines as shown in Table 12.

The relation between the reaction of plants to flag smut and stiffness of glume was also studied by X^2 for independence, as shown in Table 13. The P value between 0.30 and 0.50 indicates no association of these two characters. There were 64 beardless and 16 bearded plants and 78 red and 2 white kernels in the five smutted families of F_3. They showed normal ratios without over production of certain types.

The mean of the median date of heading of those families showing some stiff-glumed plants is 15.789 ± 0.560 and that of non-stiff-glumed plants is 14.955 ± 0.760. Their difference is 0.843 ± 0.944, which is not significant. The average date of heading of the stiff-glumed plants did not show a consistent difference from that of the non-stiff-glumed plants in the same family.

It is of interest to study the relationship between stiffness of glume and sterility in F_3 lines because there is the possibility that both characters may be due to chromosomal aberration. X^2 for independence was studied and the probability of 0.224 was obtained, as shown

TABLE 12.—*Average date of heading of smutted and smut-free plants in F_3 families.*

Family No.	Average date of heading		No. of plants	
	Smutted plants	Smut-free plants	Smutted	Smut-free
288a1-5	25	21.61	1	64
-12	8	10.64	1	42
-21	15	16.46	1	68
-32	14	15.25	3	40
-35	13.5	13.32	4	22
-45	10	11.08	1	60
-46	21	20.76	1	17
-49	12	11.03	1	66
-50	16.33	16.07	3	54
-54	17	14.97	1	69
-60	21	8.85	1	53
-67	11	17.90	1	39
-68	10	11.17	1	59
-76	18	15.18	1	50
-88	19	16.07	1	15
-96	11	11.92	1	37
288a3-3	12	14.88	2	60
-5	12	13.39	3	46
-6	14	16.92	1	49
-12	25	20.49	1	53
-20	11	11.75	7	73
-23	25	24.21	1	72
-24	18	22.83	1	63
-30	8	9.21	3	76
-33	23	22.51	2	75
-34	20	24.58	1	33
-35	9	15.15	2	80
288a4-26	23	18.43	1	72
-32	25	20.92	1	72
-35	14.4	13.47	5	74

TABLE 13.—*Probability showing whether the smut damage in the F_3 families are related to the stiffness of glume.*

Stiffness of glume	Smut-free	Smutted	Total	Chances
Normal	40	4	44	0.3636
Stiff	66	11	77	0.6364

in Table 14, indicating no association of these two characters. Thus they were due to different kinds of aberrations, or stiffness of glume was due to genes which had no association with chromosomal aberration for sterility.

TABLE 14.—*Relation between stiffness of glume and sterility in F_3 lines.*

Stiffness of glume	Sterility, %						Total No. of plants	Chances
	0	1-20	21-40	41-60	61-80	81-100		
Stiff (1)	92	5	6	1	0	2	106	0.2524
Non-stiff (2)	284	7	13	3	6	1	314	0.7476

The independent inheritance of the reaction to smut, stiffness of glume, date of heading, presence and absence of awn, and color of kernel indicates that the genes for these characters are carried in different chromosomes or at a considerable distance apart in the same chromosomes. It seems probable that different chromosomes contribute the genes for the transgressive inheritance of the reaction to flag smut, date of heading, and stiffness of glume in this cross.

SUMMARY AND CONCLUSIONS

A cross was made between a Chinese variety and Nebawa introduced from Australia. Both varieties are common wheat, *Triticum vulgare*. A genetical study was made in the F_1, F_2, F_3, and F_4 of this cross. The two parents were free from flag smut and were medium late, easy in thrashing, and fully fertile. The F_2, F_3, and F_4 of the cross gave a small percentage of susceptible plants. The genes for flag smut reaction appear to be multiple in nature.

A part of the population in F_2 headed earlier but none later than either parent. In F_3 several progenies headed significantly earlier than the early parent 4592 and a few plants in F_3 headed slightly later than the late parent, Nebawa. The genes responsible for earliness of heading seem to be multiple in nature, and the early genes are partially dominant over the late genes.

Some plants in F_2 and F_3 had stiff glumes and some were partially sterile. Transgressive inheritance of the first three pairs of characters was obtained. This is a good example of a geographically distant cross giving transgressive inheritance. The authors have obtained a similar case of transgressive inheritance in earliness from a cross between Prelude, an American variety, and Nanking 2905, a Chinese improved strain by head selection from a native variety. L. Y. Shen obtained transgressive inheritance of earliness in her crosses between Chinese and foreign varieties. Accumulation of such cases may reveal the origin of hereditary variations. Crosses of polyploid varieties may give better chances for obtaining transgressive inheritance than crosses between diploids. The segregation of partial sterile plants resulted from chromosomal aberration.

NOTE

EXTENSION OF ALFALFA ROOTS INTO SUBSOIL DRIED BY A PREVIOUS CROP

SEVERAL investigators have studied the question as to whether or not plants can extend their roots into dry soil. The conclusion has usually been that they can not do so.

In various studies reported from the Kansas Agricultural Experiment Station it has been shown that on the soil of the station farm, which is moderately heavy in the deep subsoil, alfalfa removes the water very thoroughly to depths of approximately 20 feet. It becomes of interest and practical importance to determine whether the roots of a new crop of alfalfa sown on old alfalfa land can penetrate subsoil dried by the previous crop. An experiment in which alfalfa was seeded on old alfalfa land from which subsoil moisture had been removed to about the wilting coefficient (as determined from the moisture equivalent) to depths of approximately 20 feet offered an opportunity to study this question. Plats in this experiment were fallowed for periods of time varying from one summer to 5 years before reseeding to alfalfa. At the end of the experiment the roots were investigated in a plat which had been fallowed one summer and also those in a plat fallowed 3 years. The new alfalfa stands on these plats were then 4 years old and 2 years old, respectively. Excavations were made, the hole in each plat being 12 feet square The roots were carefully worked out from one side of the hole by means of ice picks.

The data obtained from moisture samples taken at intervals throughout the experiment to a depth of 25 feet showed that the plat fallowed only one summer had accumulated water to a depth of 8 feet, or less, before the new crop was seeded. The plat fallowed 3 years had regained moisture to well above the wilting coefficient throughout the depth to which the previous crop had dried the soil. The last soil moisture samples were taken under the alfalfa sod 6 months before the roots were excavated. Experiments have repeatedly shown here, however, that there is no measurable accumulation of moisture under established alfalfa stands below a depth of about 3 feet.

In the plat fallowed one summer roots could not be traced below depths of 10 to 12 feet except where a few had entered old channels left by the decay of the roots of the previous crop and extended to a maximum depth of 17 feet. In the plat fallowed for 3 years numerous roots of the new crop could be traced to depths of 19 to 20 feet.

Since roots could not be traced beyond 20 feet, it appears that the moisture which has always been encountered at, or slightly below, this level in subsoil moisture studies under alfalfa on this soil is beyond the maximum penetration of the alfalfa roots. This conclusion is further supported by the fact that holes bored with an auger in the bottoms of these pits to a depth of 29 feet showed no permanent water table.—W. H. METZGER, *Kansas Agricultural Experiment Station*, and C. O. GRANDFIELD, *Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

BOOK REVIEW

A TEXTBOOK OF PLANT VIRUS DISEASES

By Smith, Kenneth M. Philadelphia: P. Blakiston's Son & Co., Inc. X 615 pages, illus. 1937. $5.

THREE years ago Smith wrote a book, "Recent Advances in Plant Viruses", apologizing somewhat for presenting a book when knowledge of the subject was in such a flux. He said the earlier book was no textbook, but all the usual textbook subject matter was there —nature of viruses, symptomatology, transmission, physiology, etc.

The book under review is called a textbook, but in reality it is a reference book classifying all of the plant viruses known and giving a little discussion of each, their properties, mode of transmission, etc., and the diseases they cause. The viruses are classified on the basis of the chief host plant involved. This is essentially the classification proposed by James Johnson several years ago, but improved by using the Latin name of the plant instead of the English common name which may lead to confusion. When more than one virus attacks the key host plant, the viruses are numbered consecutively. The author discusses 18 such viruses on Solanum and 15 on Nicotiana.

A very useful appendix is included where the host plants are listed alphabetically by the Latin name; the virus symptoms and their causes are listed for each. A special chapter is devoted to the insects, etc., concerned in the transmission of plant viruses, and the last chapter discusses suspected virus diseases requiring further study.

It is the opinion of the reviewer as a non-virus plant pathologist, that this is the most satisfactory and useful book on viruses yet to appear because it makes the problem of identification so simple. (J. G. H.)

FELLOWS ELECT FOR 1937

OLAF SVERRE AAMODT

Olaf Sverre Aamodt, University of Wisconsin, Madison, Wisconsin. Born at St. Paul, Minnesota, August 9, 1892. B. S. University of Minnesota, 1917; M. S. 1922; Ph.D., 1927. Scientific Assistant in Plant Pathology, Office of Cereal Investigations, U. S. Dept. of Agriculture and University of Minnesota, 1917, 1920–23. Instructor in Crop Improvement, American Expeditionary Forces in France, 1918–19. Assistant Pathologist, Office of Cereal Investigations, U. S. Dept. of Agriculture and University of Minnesota, 1921; Associate Pathologist 1923. Instructor in Genetics, University of Minnesota, 1924–26. Associate Professor of Genetics and Plant Breeding, University of Alberta, Edmonton, Alberta, 1928; Professor, 1931; Head of Department of Field Crops, 1932–35. Professor of Agronomy and Chairman Agronomy Department, University of Wisconsin, Madison, Wisconsin, 1935–.

Member American Society of Agronomy, A.A.A.S. (Fellow), American Phytopathological Society, Genetics Society of America, Western Canadian Society of Agronomy, and Canadian Society of Technical Agriculturists.

Dr. Aamodt's first important contributions were in the field of flax and cereal breeding, with special emphasis on disease resistance. These consist of numerous studies reported in scientific journals, and cooperation in the production of several successful and widely used varieties such as Redwing flax, Thatcher, and Ceres wheats and Newal barley. At present his major interests are in the agronomic phases of the conservation movement, pasture improvement, and the breeding of grasses and legumes.

He has been a member of the Society for many years and served as Chairman of the program committee for the Crops Section for 1937.

WILLIAM ALBERT ALBRECHT

William Albert Albrecht, born at Flanagan, Livingston County, Illinois, September 12, 1888. Reared on a good Illinois farm. Attended the University of Illinois, receiving an A.B. degree in 1911. Taught at Bluffton College, Bluffton, Ohio, 1911–1912. Re-entered the University of Illinois and secured the degree of B. S. in Agriculture in 1914, M.S. in Agronomy in 1915, Doctor of Philosophy in 1919. During part of this time he was assistant in botany in the University of Illinois, coming to the University of Missouri in September 1916 as instructor in soils, where he later became assistant professor, associate professor, and finally full professor.

Dr. Albrecht is a member of Alpha Zeta, Gamma Sigma Delta, Sigma Xi, Phi Kappa Phi, and an honorary member of the Farm House and Alpha Gamma Sigma fraternities. He has served in various capacities in connection with the American Society of Agronomy and was very

active in connection with the organization of the Soil Science Society of America, of which he will be Chairman in 1939.

Dr. Albrecht has given particular attention to soil biology and has between 25 and 30 publications to his credit, primarily in this field. A considerable number of graduate students have taken doctorates under his direction. Dr. Albrecht is very much interested in practical as well as scientific agriculture, owning a considerable acreage of good Illinois land. He is a very popular instructor at the University of Missouri and is a respected counselor for a large number of students.

FIRMAN EDWARD BEAR

FIRMAN EDWARD BEAR, Crowell Publishing Company, New York City. Born near Germantown, Ohio, May 21, 1884. B.S.A., Ohio State University, 1908; M.S., 1910; Ph.D., University of Wisconsin, 1917. Instructor Agricultural Chemistry, Ohio State University, 1908–1910; Assistant Professor, 1910–1913; Professor of Soils and in Charge Soil Investigations, West Virginia University, 1914–1916; Professor of Soils, Ohio State University, 1916–1929; Director Agricultural Research, American Cyanamid Company, 1929–1937; Science Editor, *The Country Home Magazine*, 1937–.

Member (Fellow) of A. A. A. S., American Society of Agronomy; Soil Science Society of America; American Chemical Society, and Sigma Xi. Special interests: Liming, nitrogen fixation, use of fertilizers, and pasture management.

Dr. Bear has served on special committees of the Society and has been a frequent contributor to the annual programs of the Society. He has been a leader in pasture management and the subject of fertilizer use, and is the author of two well-known books, "Soil Management" and "Theory and Practice in the Use of Fertilizers".

HARRY OLIVER BUCKMAN

HARRY OLIVER BUCKMAN, Cornell University, Ithaca, New York. Born on a farm near West Liberty, Iowa, July 4, 1883. B.S.A., Iowa State College, 1906; M.S., 1907; Ph.D., Cornell University, 1912; Assistant in Chemical Section, Iowa Experiment Station, 1906–7; Assistant Agronomist, Montana Experiment Station, 1907–9; Assistant Professor of Soil Technology, Cornell University, 1912–17; Professor of Soil Technology since 1917.

Member American Society of Agronomy, Soil Science Society of America, International Society of Soil Science, and the A.A.A.S. His main interest is in the field of teaching but for many years much of his attention was directed to the formation and classification of soils. He has served on various committees of the Society dealing with soil teaching and has presented a number of papers at the annual meetings.

Doctor Buckman is best known to soil scientists as co-author with Dr. T. L. Lyon of the text book, "The Nature and Properties of Soils", which has gone through several editions and which has been an outstanding contribution in its field since it first appeared in 1921.

GUY WOOLARD CONREY

GUY WOOLARD CONREY, Ohio Agricultural Experiment Station, Wooster, Ohio, and Ohio State University, Columbus, Ohio. Born Northboro, Iowa, December 10, 1887. University of Michigan A. B. in 1908, M. A. in 1909; Ohio State University Ph.D. in 1921. Assistant in Physical Chemistry, University of Michigan, 1908–1909; Assistant in Division of Soils, Wisconsin Geological and Natural History Survey, 1909–1917; Instructor in Soils, University of Wisconsin, 1914–1917; Instructor in Soils, Ohio State University, 1917–1921, Assistant Professor of Soils 1921–1926, Associate Professor of Agronomy 1930–1937, Professor of Agronomy 1937–; Assistant in Soils, Ohio Agricultural Experiment Station, 1917–1925, Associate Agronomist in Charge Soil Survey 1925–.

Member of American Society of Agronomy, Soil Science Society of America, International Society of Soil Science, American Association for the Advancement of Science, and Ohio Academy of Science. Member of Sigma Xi, Phi Lambda Upsilon, and Gamma Sigma Delta honorary societies.

Until merged with the S.S.S.A. in 1936, Dr. Conrey participated actively in the work of the American Soil Survey Association, was chairman of several important committees, and President of the Association in 1925.

Although conversant with soil science and agronomy in their broader aspects, Dr. Conrey's chief interest has centered in soil development and classification, agricultural evaluation of soils, land appraisal, and land use.

He has published numerous papers on soil genesis and morphology, and is joint author of 21 county soil survey reports, 6 in Wisconsin and 15 in Ohio.

HAROLD DeMOTT HUGHES

HAROLD DEMOTT HUGHES, Iowa State College, Ames, Iowa. Born at Antioch, Illinois, January 16, 1882. B.S., University of Illinois, 1907; M.S.A., University of Missouri, 1908; Instructor in Farm Crops, University of Missouri, 1907–1910; Professor of Farm Crops, Iowa State College and Iowa Agricultural Experiment Station, 1910–.

Member A.A.A.S., American Society of Agronomy, and Association of Official Seed Analysts (President in 1917). His special interests are legumes and grasses for hay, pasture, and green manure; pasture improvement and management. Senior author of "Crop Production". Member of Weather Bureau Committee of the President's Science Advisory Board.

Professor Hughes has been a member of the Society for many years and has served on committees on Pasture Research and Hybrid Corn.

FRANKLIN DAVID KEIM

FRANKLIN DAVID KEIM, University of Nebraska, Lincoln, Nebraska. Born at Hardy, Nebraska, September 10, 1886. B.S., University of Nebraska, 1914; M.S., University of Nebraska, 1918; Ph.D., Cornell University, 1927. Assistant Agronomist, University of Nebraska, 1914–1916; Extension Agronomist, 1917–1918; Professor of Agronomy, 1918; Acting Chairman, Department of Agronomy, 1930–1932; Chairman, Department of Agronomy, 1932 to date.

Member of A.A.A.S., American Society of Agronomy, the American Genetic Association, and Ecological Society of America. His special interests include plant breeding and genetics, research in weed control, and ecological studies of native grasses with reference to pasture and meadow utiliation.

Doctor Keim has been a member of the Society for many years and has served it on several committee assignments.

ROBERT DONALD LEWIS

ROBERT DONALD LEWIS, Ohio State University and Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Columbus, Ohio. Born Wyalusing, Pennsylvania, November 4, 1897. B.S., Pennsylvania State College, 1919; Ph.D., Cornell University, 1926. Student Assistant in Agronomy, Pennsylvania State College 1917–1919; Instructor in Agronomy, 1919–1922; University Fellow in Agriculture, Cornell University 1922–1923; Assistant in Plant Breeding, 1923–1924; Instructor in Plant Breeding, 1924–1926; Assistant Professor of Plant Breeding Extension, 1926–1930; Professor of Agronomy Extension, Ohio State University, 1930–; Associate Professor of Agronomy (resident teaching), 1933–; Agent, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. D. A., 1936–.

Member of the American Society of Agronomy, the Genetics Society of America, and fellow in the American Association for the Advancement of Science. Also a member of Sigma Xi, Alpha Zeta, Gamma Sigma Delta, and Phi Kappa Phi.

Since 1924 Dr. Lewis has been closely associated with state and national seed improvement programs. He has been Secretary-Treasurer of the Ohio Seed Improvement Association since 1930; an active member of various committees of the International Crop Improvement Association; chairman 1933 and 1934 of I. C.

I. A. Committee on Certified Seed Shows at the International Grain and Hay Show; chairman 1934 to date, I. C. I. A. Committee on Red Clover, Alfalfa, and Grass Seed Certification. Dr. Lewis was secretary, Extension Agronomists, Annual Meeting of 1933; chairman, Crops Section of the A. S. A. in 1935, A. S. A. representative on Seed Council of North America in 1937; and chairman 1937–1938 of Executive Committee of the Corn Improvement Conference.

Dr. Lewis has done outstanding work in developing action programs based upon the correlation and integration of research and extension activities in agronomy. He has also assisted in developing Ohio's approach to the problem of better land use. He has made many valuable contributions to agronomic literature, including both extension and research publications.

JAMES DOUGLASS LUCKETT

James Douglass Luckett, New York State Agricultural Experiment Station, Geneva, N. Y. Born in Washington, D. C., December 5, 1891. B. S. A., Purdue University, 1916; M. S. A., 1919. Scientific Assistant, Bureau of Entomology, U. S. Dept. of Agriculture, Vienna, Virginia, 1913–14; Assistant Chemist, Indiana State Chemist's Laboratory, Lafayette, Indiana, 1916; Editor, Field Crops Section, *Experiment Station Record*, U. S. Dept. of Agriculture, Washington, D. C., 1916–20; Editor, New York State Agricultural Experiment Station since 1920.

Member of the American Society of Agronomy, the American Association of Agricultural College Editors, Sigma Xi, and Fellow of the A. A. A. S.

Mr. Luckett served as Assistant Editor and Business Manager of the Journal of the American Society of Agronomy under Dr. R. W. Thatcher from 1924 to 1928, and has served as Editor of the Journal since 1928.

HARVEY L. WESTOVER

Harvey L. Westover, Senior Agronomist in charge of Alfalfa Investigations in the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, is a native of New York State where he spent his earlier years on a farm, graduating with the degree of B.S.A. from Cornell University in 1906. His first official appointment was as Scientific Assistant in the Bureau of Soils in 1906, in which capacity he took part in numerous soil surveys in various parts of the United States. On January 1, 1914, he transferred to what is now the Division of Forage Crops and Diseases, where in addition to alfalfa investigations, his main project, he has conducted experiments with root crops for livestock, silages, and turf grasses. He is a recognized authority on alfalfa in the United States and has published widely on this and other subjects.

Westover has taken part in several plant exploration expeditions. In 1924 he was sent to Argentina and Chile in search of new alfalfas; in 1929 to Russian Turkistan and continental Europe, and in 1930 to Spain and North Africa in search of alfalfas resistant to bacterial wilt; in 1934 to Turkistan and Turkey in search of plants for erosion control; and in 1936 to Turkey in search of new forage crops, vegetables, and ornamentals. More than 6,000 introductions resulted from these expeditions. Many lots of alfalfa seed obtained from Turkistan have proved highly resistant to bacterial wilt and are being used in the breeding program. In the preliminary trials other legumes and grasses appear promising for various purposes in the United States.

In 1934, Westover was Chairman of the Crops Section of the American Society of Agronomy, in which capacity he served until about May 1, when his official duties took him to Russia. He is Permanent Secretary of the Alfalfa Improvement Conference, and in 1937 was a member of the committee on alfalfa, clovers, and grasses of the International Crop Improvement Association. From 1927 to 1932 he was a member of the research committee and the executive committee of the United States Golf Association Green Section, serving as Acting Chairman of the former from 1927 to 1929.

He is a fellow of the American Association for the Advancement of Science, a member of the American Museum of Natural History, American Forestry Association, National Geographic Society, the Botanical Society of Washington, the Cosmos Club, and the Explorers Club.

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PRELIMINARY PROGRAM OF MEETINGS OF THIRD COMMISSION ON SOIL MICROBIOLOGY OF INTERNATIONAL SOCIETY OF SOIL SCIENCE

THE preliminary meetings of the Third Commission on Soil Microbiology of the International Society of Soil Science, will be held in New Brunswick, New Jersey, on Wednesday, August 30, 1939. The meetings will last until Saturday or the date of the beginning of the Third International Microbiological Congress which is to be held in New York City on September 2, 1939. The meetings of the Commission on Soil Microbiology are arranged in cooperation with Section VIII on Agricultural and Industrial Microbiology of the Microbiological Congress.

The following subjects will be considered at the meeting of the Third Commission: (1) Legume bacteria; (2) microbiology of organic matter decomposition; and (3) the soil population. Titles of papers to be presented before this Commission should be submitted not later than July 1, 1938. The complete papers should be sent in before January 1, 1939. It is hoped that these papers will be published in a volume of Proceedings, before the meetings.

All correspondence concerning these meetings should be addressed either to Dr. H. G. Thornton, Rothamsted Experimental Station, Harpenden, England, or Dr. S. A. Waksman, New Jersey Agricultural Experiment Station, New Brunswick, N. J.

MEETING OF AGRONOMISTS INTERESTED IN BARLEY GENETICS

ON the afternoon of December 1, 1937, at the Stevens Hotel in Chicago was held a meeting of agronomists interested in barley genetics. At that time an informal organization of workers in the field of barley genetics was formed with D. W. Robertson appointed as Secretary.

A summary of the present linkage work on barley will be prepared and furnished the various workers in the field. An additional committee was appointed, comprising G. A. Wiebe and D. W. Robertson, to revise the nomenclature and allot new symbols as new characters are found and their inheritance determined.

It is hoped that the organization will act as a clearing house for workers in barley genetics. Where possible, linkage groups and characters will be allotted among the workers in an attempt to prevent duplication and in order to verify the results obtained.

NEWS ITEMS

W. T. G. WIENER, Secretary-Treasurer of the Canadian Seed Growers' Association of Ottawa, Canada, was elected President, for a two-year term, of the International Crop Improvement Association at a meeting of the Association held in Chicago, Ill., November 30, 1937.

DR. A. J. PIETERS, formerly Principal Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, has been granted a year's extension in the service by the President and transferred to the Soil Conservation Service where he will be engaged during the coming year in a study of *Lespedeza*.

DR. R. H. WALKER, Conservationist at the Intermountain Forest and Range Experiment Station was recently elected Director of the Agricultural Experiment Station at the Utah State Agricultural College, Logan, Utah, where he will assume his new duties after March 1. Dr. Walker was formerly a member of the staff as Assistant Professor of Agronomy at the Colorado State Agricultural College, and from 1928 to 1936 was Research Associate Professor of Soils at Iowa State College, where he was in charge of the soil bacteriological investigations. At the Intermountain station he has had charge of the artificial reseeding investigations in the division of range research.

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OXIDATION-REDUCTION POTENTIALS IN ORCHARD SOILS[1]

R. E. STEPHENSON, C. E. SCHUSTER, AND JOE SPULNIK[2]

ORCHARD soils studied at the Oregon Agricultural Experiment Station (7)[3] have shown great variation in physical properties, texture, structure, and aeration. Root distribution and variations in tree growth were found to be correlated with soil conditions. The deep soil horizons of some heavy soils appeared to be anaerobic during a greater part of the season. This condition raised the question as to whether such soils would show low oxidation-reduction potentials, which correlate with their lack of suitability for root development and tree growth.

HISTORICAL

A good review of the literature concerning the relation of oxidation-reduction potentials to the properties and conditions of soils has been made by Bradfield and associates (1) and by Sturgis (8). Willis (9), Peech and Batjer (6), Bradfield and others (1), and Brown (2) have given improved methods for the study of oxidation-reduction potentials of soils.

Darnell and Eisenmenger (3) have reported that rapid decomposition of organic matter in the soil brought about a marked fall of potential, and they attributed this to oxygen depletion. They conclude that change in acidity, resulting from biological processes associated with the breaking down of fresh organic matter, and a reduction in the oxygen supply are the chief causes of reduced potentials in soils.

Heintze (4) questions the diagnostic value of oxidation-reduction measurements on soils.

METHODS OF STUDY

Soil samples were collected by 1-foot horizons, except the surface foot which was in two 6-inch sections. Samples of the soil were suspended in N/10 H_2SO_4,

[1]Published as Technical paper No. 276 with the approval of the Director of the Oregon Agricultural Experiment Station, Corvallis, Ore. Contribution from the Soils Department in cooperation with the U. S. Department of Agriculture. Received for publication November 1, 1937.

[2]Associate Professor of Soils, Oregon Agricultural Experiment Station; Horticulturist U. S. Dept. of Agriculture; and Laboratory Assistant, Oregon Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 96.

and the redox potential determined according to the method of Bradfield and associates (1).

In some cases soil samples were taken and suspended immediately in the H_2SO_4 solution in the field. Other samples were brought to the laboratory and later prepared for study. The results were practically the same with the various methods of handling.

Both plate and stiff wire electrodes of bright platinum were used. The electrodes were carefully cleaned in nitric acid, ammonia, and cleaning solution, and checked against each other. They were then left to age in a soil suspension until readings were to be taken. The pH was determined with quinhydrone and samples were checked a number of times.

The cell used for the redox measurement was:

Hg | Hg_2Cl_2(S) KCl (sat) || soil suspension | Pt.

The basic equations for obtaining the potential are:

$$E_h = E_o + \frac{RT}{nF} \ln \frac{(\text{oxidant})}{(\text{reductant})}$$

$$E_t = E_h - E_{cal.}$$

E_t = Total E.M.F. measured.

$E_{cal.}$ = E.M.F. of calomel half cell.

E_h = Oxidation of reduction potential.

The theory of measurement of oxidation-reduction potentials is discussed by Brown (2), also by Peech and Batjer (6) and others (1, 3, 8, 9).

RESULTS OF STUDY

Some of the soils under study possess tight subsoil horizons. The redox potential on the different horizons does not vary much as indicated by the data of Table 1, which gives the oxidation-reduction potential for an Amity clay loam taken from a Persian walnut orchard on April 14, 1936. This soil was sampled again the last of April and once more the middle of May, and the redox determinations did not show any appreciable change in the oxidation-reduction potentials for any of the horizons and therefore the data are not given. Apparently, oxidation-reduction processes, if active in any horizon of this soil, did not result in a low potential, as indicated by present methods of measurement.

TABLE 1.—*Redox potentials of an Amity clay loam soil, sampled April 14, 1936.*

Soil horizon, inches	E.M.F., volts	pH	Eh volts	Eh @ pH 3, volts*
0–6	0.50	2.3	0.75	0.69
6–12	0.50	2.4	0.75	0.70
12–24	0.50	2.3	0.75	0.69
24–36	0.51	2.3	0.76	0.70
36–48	0.50	2.5	0.75	0.71
48–60	0.48	2.5	0.73	0.69
60–72	0.50	2.3	0.75	0.69

*80 m.v. per pH was used to correct the E_h to pH 3.0. This value was used by Bradfield and associates (1). When checked in our work the 80 m.v. of Bradfield rather than the standard 59 m.v. proved correct.

A number of productive, moderately productive, and nonproductive orchard soils were studied to determine the differences in the oxidation-reduction potential of the different soils and the different horizons of the same soil. The data for the redox potentials, E_h at pH 3.0 of these soils and horizons, are given in Table 2. These data show that there was no outstanding difference in the oxidation-reduction potentials in any of the soils or horizons studied, even in the case of the Wapato soil which was sampled from an area which was wet at the time of sampling and which is known to remain in that condition throughout most of the season. The redox potential was practically the same as the well-drained and aerated horizons of the Newberg or Willamette soils. Peech and Boynton (5) find that active forms of manganese concretions in the soil cause rapid oxidations and thus prevent low redox potential readings in poorly drained subsoils.

TABLE 2.—*The redox potentials in volts, E_h at pH 3.0, of different horizons of seven soil series.*

Soil horizon, inches	Melbourne	Salkum	Newberg	Carlton	Willamette	Chehalis	Wapato
0–6	0.58	0.65	0.64	0.67	0.74	0.72	0.70
6–12. . . .	0.64	0.66	0.68	0.69	0.71	0.60	0.65
12–24	0.64	0.65	0.67	0.71	0.75	0.74	0.73
24–36. . .	0.72	0.65	0.69	—	0.74	0.73	0.74
36-48. . . .	0.63	0.65	0.74	0.72	0.72	0.72	0.72
48–60. . . .	0.67	0.67	0.74	0.63	0.76	0.75	0.76
60–72 . . .	0.64	0.68	0.73	0.72	0.76	0.75	0.75
72–84 .	0.62	0.69	0.70	0.73	0.76	0.73	—

Samples of a Newberg sandy loam were treated with different materials according to the plan given in Table 3. These samples were watered at different rates and incubated for a varying number of days at room temperature. The samples containing both the 75 and 100% moisture contents were water-logged. This Newberg soil normally has a redox potential of 0.70 volt plus or minus. The data indicate that 35% moisture produced enough water logging to result in reduction by dextrose. Reduction occurred in the presence of straw and alfalfa with heavy watering, but not with 25% moisture. The 35% moisture did not cause reduction except in the presence of dextrose.

The limestone does not appear to have a significant effect in any case. Waterlogging in the presence of fresh organic matter appears responsible for whatever changes occur. There is no consistent difference in the effect of low protein material such as straw and the higher protein material such as alfalfa. Such reductions as may occur in the field under reducing conditions which may prevail temporarily, disappear as the soil dries. This is indicated by the oxidations indicated in Table 3 as the soil slowly dried in the laboratory.

DISCUSSION

The data indicate that while there may be some difference in the degree of oxidation of various western Oregon soils, the difference is not marked. The climate of western Oregon is such that the moisture of the root zone is well removed by plants during the growing season.

TABLE 3.—*E_h at pH 3.0 in volts on Newberg sandy loam, A series in duplicate, B and C series singly.**

A Series

Soil treatment	Water %	After incubation for			
		5 days	17 days	26 days	37 days
1. $CaCO_3$+Dextrose, 1%	35	0.57	0.54	0.49	0.56
		0.57	0.55	0.53	0.49
2. $CaCO_3$, 1%	35	0.74	0.65	0.70	0.68
		0.71	0.66	0.70	0.73
3. Dextrose, 1%	35	0.58	0.52	0.46	0.50
		0.58	0.55	0.48	0.50

B Series

Soil treatment	Water %	After incubation for				Dried 22 days
		5 days	12 days	21 days	33 days	
1. Ground alfalfa, 3%	75	0.49	0.49	0.45	0.43	0.54
2. $CaCO_3$, 1%+ Alfalfa, 3%	75	0.50	0.49	0.47	0.42	0.55
3. $CaCO_3$, 1½%+ Alfalfa, 7%	100	0.50	0.45	0.42	0.39	0.57
4. Ground straw, 3%	100	0.53	0.52	0.46	0.45	0.60
5. $CaCO_3$, 1½%+ Straw, 3%	100	0.51	0.55	0.42	0.39	0.58
6. $CaCO_3$, 1½%+ Straw, 3%	100	0.45	0.46	0.42	0.39	0.57

C Series

Soil treatment	Water %	After incubation for			
		5 days	19 days	26 days	33 days
1. $CaCO_3$, 1%	25	0.70	0.74	0.70	0.71
2. $CaCO_3$, 1%+Straw, 3%	25	0.73	0.72	0.65	0.69
3. Straw, 1½%	25	0.68	0.71	0.66	0.64
4. $CaCO_3$+Alfalfa, 1½%	25	0.70	0.70	0.67	0.68
5. Alfalfa, 1½%	25	0.75	0.69	0.66	0.66

*E_h at pH 3.0 on this soil was 0.70 volt ±before any reduction occurred.

The fall rains carry oxygen-laden moisture gradually deeper into the soil. Conditions are favorable, therefore, at certain periods of the year for oxidation processes which produce an oxidized condition in most of the soil types used for agriculture.

The conclusion seems justified that waterlogging may exist in tight subsoil layers without any very active reduction taking place. There is little organic matter in the subsoil, and biological action is limited. A study of the distribution of micro-organisms in the soil profile of these soils in the field indicates that most of the bacteria and fungi are in the top 12 to 24 inches of soil which in all cases is fairly well

aerated. The easy access of air (oxygen) to the surface horizons where fresh organic matter and micro-organisms are present largely prevents reduction of the soil mass in this area. In the deep soil where oxygen may be excluded at times, reduction is not active because of lack of fresh organic matter and organisms.

That the combination of fresh organic matter and waterlogging may bring about reduction is indicated by the data of Table 3. The data indicate that low potentials are obtained only while waterlogging occurs. When there is no waterlogging, decomposition occurs without marked lowering of potential. A reduced soil left to dry regains its oxidized condition in the course of time. The rate of recovery may be slow, however.

Reducing conditions which may exist in the soil are unfavorable to plant growth regardless of whether or not a low redox potential is produced. The well drained, aerated and oxidized soils supply oxidizing conditions and incidentally high potentials. Such a condition is favorable to plant growth. This conclusion is based upon the growth of plants in the field where the soil samples were obtained.

Reduced soils may occur under natural conditions, but cultivated soils of western Oregon studied thus far have not shown a low potential. Yet oxidizing conditions in the soil are essential to those processes, such as nitrification, sulfofication, and others, which prepare plant nutrients for root absorption. There can be little doubt as to the importance of oxidizing conditions in the soil for plant growth.

Peech and Batjer (6) state that practically no reduction occurs in the spring until the soil reaches a temperature of 55° F. Under western Oregon conditions by the time the soils have warmed sufficiently, rains have stopped and waterlogging, except in the subsoil, has disappeared. With aerobic conditions in the zone of humus accumulation, and with biological action, there is perhaps little cause for active reduction processes.

The possibility of an oxidizing agent in the soil, as suggested by Peech and Boynton (5), which is activated by treatments made in the process of determining the oxidation-reduction potential must not be overlooked. The state of reduction of the soil because of inadequacy of methods used under such conditions would not be correctly interpreted. That there are soils of low oxidation-reduction potentials is without question, but the use of present methods in distinguishing waterlogged horizons has been disappointing. Likewise it has not been possible in this study to distinguish the less productive from the more productive soils.

SUMMARY

1. Different soil types under field conditions have shown little variation in oxidation-reduction potentials with the methods used.

2. Different horizons of the soil, even where there is a tight subsoil, show little variation in oxidation-reduction potential.

3. Fresh organic matter alone in moist soil does not cause a fall in the potential.

4. Fresh organic matter with a waterlogged condition causes a rapid fall of potential.

5. The oxidation-reduction potential is not a dependable indication of anaerobic conditions in the soil.

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THE EFFECT OF APPLICATIONS OF COMMON SALT UPON THE YIELD AND QUALITY OF SUGAR BEETS AND UPON THE COMPOSITION OF THE ASH[1]

J. G. LILL, S. BYALL, AND L. A. HURST[2]

FOR many years farmers have been interested in results from salt applications to sugar beets. Tests conducted by Brock (1)[3] showed that, in several years of trial, the use of salt had increased stand, yield, and sucrose percentage over the results from comparable areas not receiving salt. In these tests, commercial fertilizers were used with and without salt, and in some cases only salt was applied. As a result of this report many Michigan beet growers, especially in that portion of the state where salt could be secured cheaply and in quantity, have applied salt to the soil each year for their sugar beet crop. No accurate figures can be obtained as to the acreage treated, nor the total amount of salt used, although both of these totals are known to be large.

Agricultural literature contains many references to experiments with salt as a soil amendment on many different crops. Townsend, cited by Saylor (6), reported Michigan tests in which a 200-pound-per-acre application of salt had increased the yield of beets from 8.69 tons per acre to 11.18 tons. Other Michigan tests of the same general nature are on record.

In 1909, Mette (5) found that, "The yield of beets on plots receiving salt was increased 2,312 kg. per hectare (about 2,058 pounds per acre) over the yield on the plots not so treated. The average sucrose content of the beets on the plots receiving salt was 21.48 per cent as compared to 20.58 per cent for the beets on the check plots."

De Ruijter de Wildt and Mol (2) observed that, "In a third test, sugar beets were grown on land that had been flooded with sea water and contained, as shown by analysis, 35,000 kg. of common salt per hectare to a depth of 60 cm. The composition of these beets showed that the salt content of the soil had reduced the sugar content, changed the relationship of potassium and sodium by greatly increasing the sodium content, and had increased the chlorine and ash content."

In 1915, Tottingham (7) found that soil cultures of sugar beets in greenhouse where sodium chloride was supplied have exceeded the control in yield. Also, in plat experiments in the field with sugar beets at Madison, Wis., an increase in yield was secured by the use of sodium chloride.

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[1]Contribution from the Farm Crops Section of the Michigan Agricultural Experiment Station, East Lansing, Mich.; the Carbohydrate Research Division, Bureau of Chemistry and Soils; and the Divisions of Soil Fertility Investigations and of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Received for publication November 6, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 106.

In 1921, Hoffman (3) wrote, "Common salt and generally most sodium salts increased the quantity and quality of the sugar-beet crop on both light and heavy soils where only light applications of potash had been made and heavy sodium fertilization had been practiced." And: "It was found that the use of sodium reduced evaporation and increased the water-holding power of the soil. It is also thought that through an exchange of bases it is capable of rendering certain relatively insoluble nutritive salts more available to the plants."

In 1936, Egorov (4) reported a resumé of the Charkower Agricultural Technical School field experiments from 1917 to 1935 concerning the action on beets of sodium chloride and manganese sulfate in addition to complete mineral fertilization. According to this resumé, in 14 out of 18 years, the use of sodium chloride increased the yield. The average increase for the use of the sodium chloride was reported as 32.6% for the weight of roots and 38% for the amount of sugar produced per surface unit area.

In 1930, the Michigan State Agricultural Experiment Station and the U. S. Dept. of Agriculture began experiments to determine the effects on the sugar beet crop of applications of common salt. In these experiments salt of "water-softener" grade was used.[4] Beginning with the 1934 experiments, juice from the beets produced under the various treatments was analyzed by the Carbohydrate Research Division, Bureau of Chemistry and Soils, to determine the effect of the salt applications upon the various constituents of the ash of the sugar beet. This work has now been carried to such a point that report is desirable.

EXPERIMENTAL RESULTS[5]

In 1930, as part of the extensive series of fertilizer trials on the O'Keefe farm of the Michigan Sugar Company, near Saginaw, Mich., salt was applied at the rate of 500 pounds per acre to certain plats in this experiment. These plats were in systematic arrangement, four plats being end to end and each of these four plats receiving the same treatment whether it were fertilizer alone or fertilizer with salt in addition. On either side of these sets of four plats, which received salt or salt and fertilizer, were check plats also in sets of four and end to end. The results secured on these sets of plats have been averaged for each treatment and for the two sets of check plats, independently, and are presented in Table 1. No attempt has been made to calculate any statistical factors for these results.

Due to the systematic arrangement of the plats in this experiment, it is better to regard the results as having been secured from individual plats for each treatment, although all values were determined for each plat of each treatment separately and the results averaged to determine the effect of the treatment. From the comparisons with

[4]Results of an analysis of a typical sample of this grade of common salt were as follows: Sodium chloride, 96.64%; moisture, 0.20%; undetermined, 3.16.

[5]In agricultural practice, salt is broadcast and harrowed into the soil prior to planting. This method was followed in 1931 when the salt was applied in bands of definite width crossing the field. For the other experiments, the salt was broadcast by hand on the surface of the soil at the specified rates immediately following planting. Commercial fertilizers were drilled in with the seed except for the 1936 test, in which the fertilizer was broadcast by hand in the same manner as the salt after the plats were planted.

TABLE 1.—*Effect of salt applications with and without fertilizer on the sugar beet crop on the O'Keefe farm, Saginaw, Mich., 1930, with the results given as four-plat averages.*

Amount and kind of materials applied per acre	Commercial roots, per acre, no.	Acre-yield of roots, tons	Sucrose %	Apparent purity coefficient	Calculated sugar production per acre, lbs.*	
					Gross	Indicated-available
Nothing	10,839	5.946	19.26	87.57	2,290	2,006
300 lbs. 4-12-4 fertilizer	14,553	10.154	19.64	86.07	3,989	3,441
300 lbs. 4-12-4 fertilizer and 500 lbs. salt	15,239	11.103	19.55	86.43	4,307	3,725
300 lbs. 4-4-12 fertilizer	14,389	8.719	19.06	87.26	3,323	2,900
300 lbs. 4-4-12 fertilizer and 500 lbs. salt	15,765	11.557	19.48	87.72	4,503	3,948
500 lbs. salt	13,948	9.349	19.70	86.60	3,683	3,187
Nothing	9,628	6.328	19.60	86.63	2,481	2,149

*The results shown are the averages of the values, determined individually, for the four plats of each set, hence differing slightly from the product of the means shown in the table.

the untreated plats lying on either side of the sets receiving salt alone and with the plats that received both salt and fertilizer lying immediately adjacent to a plat that received only the fertilizer, it seems evident that the application of salt to the soil for the sugar beets had a marked beneficial effect upon the crop.

Accordingly, in 1931, the experimental work with salt was carried out on a larger scale. As in the previous year, this work was combined with an extensive series of fertilizer tests and was located not only upon the O'Keefe farm of the Michigan Sugar Company but also upon the Merrill farm of the Holland-St. Louis Sugar Company. In both these series of tests, a number of plats, lying in pairs, received identical treatments. There were 20 such pairs in the series on the O'Keefe farm and 13 on the Merrill farm. One plat of each pair was an unfertilized check, while the other plat received an application of a 4-12-4 fertilizer at the rate of 300 pounds per acre. The fertilized plats and the check plats were divided into four sub-plats, every other sub-plat receiving salt at the rate of 500 pounds per acre. Thus half of the area of each plat in this series was salted.

Salted sub-plats of each unfertilized plat lay immediately adjacent to salted sub-plats of each fertilized plat and the unsalted sub-plats were likewise immediately adjacent to each other. In determining the influence of the application of salt upon the results, the values for the salted sub-plats of each plat were totalled for a comparison with the total of the values of the unsalted sub-plats.

While such an arrangement of plats is entirely systematic, the results are admirably suited to a determination of their statistical reliability by Students' method of paired comparisons. Such deter-

minations have been made for the results secured from the salted and unsalted sections of both the check plats and those plats receiving the 4–12–4 fertilizer. These determinations, however, have been made only for the calculated gross-sugar production.

Table 2 gives the results secured in 1931 in summary form, together with the statistical reliability of the calculated gross-sugar production indicated.

TABLE 2.—*Effect of salt applications with and without fertilizer on the sugar beet crop, O'Keefe farm, Saginaw, Mich., and the Merrill farm, Merrill, Mich., 1931.*

Amount and kind of materials applied per acre	Commercial roots per acre, no.	Acre-yield of roots, tons	Sucrose %	Apparent purity coefficient	Calculated gross sugar produced per acre, lbs.*	Odds that salt had favorable effect
			O'Keefe Farm			
No commercial fertilizer applied:						
500 lbs. salt...	18,249	15.212	15.55	84.42	4,721	
Without salt..	17,470	13.514	15.56	84.95	4,208	
Difference§	779	1.698	−.01	−.53	513	9,999 to 1†
Commercial fertilizer applied:						
300 lbs. 4–12–4 plus 500 lbs. salt........	19,729	16.580	15.77	84.65	5,224	
300 lbs. 4–12–4 only.......	19,901	16.197	15.44	85.14	5,005	
Difference§	−172	0.383	0.33	−0.49	219	31 to 1†
			Merrill Farm			
No commercial fertilizer applied:						
500 lbs. salt...	11,171	11.107	13.00	82.57	2,878	
Without salt..	9,749	9.214	13.42	82.91	2,475	
Difference§	1,422	1.993	−0.42	−0.34	403	830 to 1‡
Commercial fertilizer applied:						
300 lbs. 4–12–4 plus 500 lbs. salt........	11,905	12.394	13.24	82.38	3,265	
300 lbs. 4–12–4 only.......	11,141	10.894	13.60	83.61	2,950	
Difference§	764	1.500	−0.36	−1.23	315	226 to 1‡

*The results shown are the averages of the individual plat values, hence differ slightly from the product of the means shown in the table.
†Based on 20 paired plats.
‡Based on 13 paired plats.
§Differences unfavorable to salt are indicated by minus sign.

While the benefit derived from the application of salt to the soil for the sugar beets in 1931 is not nearly so marked as the benefit that had been secured in 1930, the effect of the salt was positive and definite. It is very interesting to note that the influence of the salt applied to the fertilized plats was less in actual amount and less in consistency than where the salt had been applied to unfertilized soil, the consistency of the comparison differences being shown by the size of the odds that the salt had had a beneficial effect.

Although this work was carried on during the seasons of 1932 and 1933, unfavorable conditions and other factors rendered the results worthless.

In 1934, the work was continued in the form of a 5 x 5 Latin square on the Merrill farm of the St. Louis Sugar Company (leased from Holland-St. Louis Co.). Variations in the amount of salt applied were used for the first time for a comparison of the effect of the various amounts applied as well as a comparison with the results secured without any salt. No fertilizer was applied to the soil where the experiment was conducted. The results secured in this experiment were evaluated according to the principles of the analysis of variance and are shown together with the statistical factors determined in Table 3.

TABLE 3.—*Effect of salt applications on sugar beets, Merrill farm, Merrill, Mich., 1934, with the results given as five-plat averages.*

Amount of salt applied per acre, lbs.	Commercial roots per acre, no.	Acre-yield of roots, tons	Sucrose %	Apparent purity coefficient	Calculated sugar production per acre, lbs.*	
					Gross	Indicated-available
None	11,737	7.502	13.03	86.87	1,994	1,739
250	12,126	8.416	12.51	81.90	2,160	1,781
500	13,075	9.264	12.88	82.55	2,402	1,989
750	13,293	9.288	13.04	82.48	2,460	2,044
1,000	14,498	11.220	12.91	83.09	2,904	2,415
Difference required for significance	Not significant	1.605 (1%)†	Not significant	1.31 (1%)†	479 (5%)†	Not significant

*The results presented are averages of the individual values determined for each of the five plats of each treatment, hence the table will not cross check.

†Values given as required for significance at 1% point indicate that when differences as great as these exist between two averages, the odds are 1 in 100 that so great a difference could have occurred by chance; similarly, when the 5% point is taken, this indicates the odds of chance occurrence as 1 in 20.

The statistical reliability of the above results was greatly diminished by the wide variations in the yield of the individual plats under the various treatments but, when the averages are considered, the yield secured and the calculated gross and indicated-available sugar increased with the increase in the amount of salt applied. The sucrose content of the beets and the apparent purity coefficient were adversely affected, but the application of 250 pounds of salt apparently had as great an adverse effect upon these two factors as the application of 1,000 pounds. The reduction in the sucrose percentage of the beets

and the apparent purity coefficient were not sufficient, however, to offset the favorable effect upon the yield.

The experiment was continued in 1935, but the area was flooded about the time the beets were thinned and the entire stand was lost.

In 1936, the work was expanded to a 6 x 6 Latin square and included, besides the various salt treatments, a set of plats that received an application of 500 pounds of a 2-10-6 fertilizer but did not receive any salt. The results of this test are shown in Table 4.

TABLE 4.—*Effect of salt applications on sugar beets, Merrill farm, Merrill, Mich., 1936, with the results given as six-plat averages.*

Treatment given per acre	Commercial roots per acre, no.	Acre-yield of roots, tons	Sucrose %	Apparent purity coefficient	Calculated sugar production per acre, lbs.*	
					Gross	Indicated-available
None	13,765	8.387	14.91	88.17	2,513	2,185
250 lbs. of salt	16,537	11.452	14.52	88.28	3,324	2,938
500 lbs. of salt	15,967	12.205	14.86	88.76	3,644	3,230
750 lbs. of salt	16,981	13.464	14.80	87.19	3,991	3,479
1,000 lbs. of salt	16,695	12.537	14.96	87.80	3,777	3,313
500 lbs. of 2-10-6 fertilizer	17,012	14.351	15.24	89.43	4,386	3,922
Difference required for significance	1,453 (1%)†	2.129 (1%)†	Not significant‡	Not significant‡	712 (1%)†	616 (1%)†

*The values given for each treatment are the averages of the determinations made on each of the six plats, hence differ slightly from the product of means given in table.

†Values given as required for significance at 1% point indicate that when differences as great as these exist between two averages, the odds are 1 in 100 that so great a difference could have occurred by chance.

‡Variance assignable to treatment did not reach significant amount

The results secured in 1936, while not entirely in accord with the results that had been obtained in previous years, again demonstrated the favorable effect of the salt applied to the soil upon the sugar beet crop, although the beneficial effect of salt applications is overshadowed by the beneficial effect of fertilizer applied without salt. In 1936 the results were significant for stand, yield, and calculated sugar production per acre, but not significant for sucrose percentage of the sugar beets nor for the apparent purity factor of the sugar beet juice.

When the beets were harvested from the salt test plats in both 1934 and 1936, three samples of 20 beets each were taken from each plat for a determination of the quality of the beets produced. From these samples, a quantity of juice was obtained representing each of the various treatments given. In order to secure this juice so that it would be as representative as possible, each of the three samples from any one plat was pulped and pressed separately and the same amount of juice was taken from each of the three samples to make the final sample of juice representing that certain plat.[6] After the addition of a suitable preservative, the samples of juice were sent to the Carbo-

[6]Acknowledgment is due J. E. Kotila for preparation of the samples used in the 1936 tests.

hydrate Research Division of the U. S. Dept. of Agriculture where a critical analysis of the ash of the juice was made to determine the effect of the application of salt upon the composition of the ash.[7]

In 1934, five analyses were made of the juice of the beets grown on each of the different treatments. In 1936, due to the inclusion of the sixth series of plats that received the fertilizer treatment, the number of analyses made for each treatment was increased to six. The results of the analysis of the ash of the juice of the sugar beets are given in Table 5.

The most important of the changes that occurred in the ash and the only ones that were found to be statistically significant for both 1934 and 1936 occurred in the sodium and chlorine contents. In both years, it was found that the sodium and the chlorine contents increased with the increasing amount of salt applied to the soil, indicating that the greater the amount of salt applied, the greater would be these ash constituents.

There were other changes in the ash constituents, however, that are of interest, even though the results were not found to be significant. With the increasing amounts of salt applied, the total ash was found to increase. This would account in some measure for the lowering of the apparent purity coefficient of the juice of the sugar beets after the application of salt to the soil. The phosphoric acid content of the ash of the beet juice is apparently unaffected by the application of salt but is changed by the application of phosphoric-acid-containing mixtures. This resulted in the data being found significantly different for this constituent in 1936.

But the point that is of greatest interest in the 1936 results, even though the data relating to it were not found to be statistically significant, is the change in the potash content of the ash of the sugar beet juice when salt had been applied in varying amounts and when potash-carrying fertilizer had been applied but with no salt. As the amount of salt applied increased, the potash content of the ash increased in some measure over the potash content of the ash of beets from the untreated plats. This is especially interesting in view of the fact that the potash content of the ash of the beets from the plats that had received an application of potash-carrying fertilizer had not increased perceptibly. The increase in the potash content of the ash that may be credited to the application of the salt ranged from a difference of 0.13 between the untreated and the 250-pound application to a difference of 0.22 between the untreated and the 750-pound application.

There is indication from this that, in comparison with those sugar beets grown with potash supplied directly from the potash-carrying fertilizer, more potash was taken up by the sugar beet from the soil when salt had been applied.

[7]Potassium oxide was determined by a modification of the cobaltinitrite method of Amsterweil and Lemay (Bul. Soc. Chem., 49:1541, 1931); and sodium oxide by the method of Barber and Kolthoff (Jour. Amer. Chem. Soc., 50:1625, 1928). Other determinations were by A. O. A. C. methods as used by the Carbohydrate Research Division in determining ash constituents of white sugars.

TABLE 5.—*Results of analysis of the ash of juice of sugar beets grown on the salt-treatment plats, Merrill farm, Merrill, Mich., 1934 and 1936, with the results for 1934 given as five-sample averages and those for 1936, as six-sample averages.**

Treatment of plats stated on acre basis	Total solids† %	Total ash %	Silicon dioxide %	Sulphur trioxide %	Calcium oxide %	Phosphoric acid %	Chlorine %	Sodium dioxide %	Potash %	Total nitrogen %
					1934					
No salt	16.7	3.25	0.19	0.12	0.15	0.18	0.12	0.15	1.51	0.952
250 lbs. of salt	16.4	3.68	0.10	0.13	0.12	0.19	0.35	0.37	1.65	0.953
500 lbs. of salt	16.6	3.65	0.11	0.12	0.12	0.19	0.43	0.39	1.57	0.933
750 lbs. of salt	16.9	3.83	0.13	0.12	0.13	0.17	0.49	0.41	1.59	0.908
1,000 lbs. of salt	16.7	4.02	0.12	0.11	0.13	0.17	0.58	0.50	1.67	0.878
Difference required for significance	Not significant	Not significant	.02 (1%)‡	Not significant	.01 (1%)‡	Not significant	.08 (1%)‡	.08 (1%)‡	Not significant	Not significant
					1936					
No salt	16.15	3.67	0.04	0.09	0.14	0.15	0.30	0.27	1.61	0.730
250 lbs. of salt	15.88	4.03	0.04	0.09	0.13	0.14	0.54	0.35	1.74	0.770
500 lbs. of salt	15.88	4.26	0.03	0.09	0.15	0.15	0.65	0.41	1.78	0.760
750 lbs. of salt	15.99	4.29	0.03	0.09	0.15	0.15	0.72	0.43	1.83	0.740
1,000 lbs. of salt	16.16	4.27	0.04	0.09	0.14	0.16	0.70	0.44	1.78	0.760
500 lbs. 2–10–6 fertilizer	16.34	3.57	0.03	0.10	0.15	0.26	0.40	0.24	1.63	0.740
Difference required for significance	Not significant	0.51 (5%)‡	Not significant	Not significant	Not significant	0.01 (1%)‡	0.12 (1%)‡	0.12 (5%)‡	Not significant	Not significant

*The data for ash, ingredients of the ash, and total nitrogen were calculated to dry substance basis.
†By drying.
‡Values given as required for significance at 1% point indicate that when differences as great as these exist between two averages, the odds are 1 in 100 that so great a difference could have occurred by chance; similarly, when the 5% point is taken, this indicates the odds of chance occurrence as 1 in 20.

DISCUSSION

With the results of the experiments carried out in practically entire agreement with the results reported by other observers, it must be recognized that common salt when applied to the soil for the sugar beet crop has had, in general, under many different conditions, a beneficial effect. This beneficial effect has been noted on the stand or the number of commercial roots secured, the yield, and, in many cases, on the calculated gross and indicated-available sugar. Sucrose percentages of the sugar beets produced were not significantly influenced in these tests. However, with the apparent purity coefficient of the sugar beet juice, the results have been in the greater number of instances that the ratio is lowered to some extent. This adverse effect upon the apparent purity coefficient has usually not been sufficient to offset the advantage of the increased yield when the amounts of indicated-available sugar have been calculated.

What effect the changes in the ash constituents would have on the refining of the sugar is not known, although it is widely recognized that both the chlorine and the sodium have a marked melassigenic effect. But the application of the salt not only lowered the apparent purity coefficient of the juice of the beets produced but also increased the amount of chlorine and sodium in the ash. It would seem, therefore, that the application of salt to the soil for the beet crop would increase the difficulty of refining the sugar and would also lower the proportion that could be secured.

Since common salt is not recognized as contributing essential plant food material, the beneficial effects noted may be due to a large extent to the effect that salt has upon the plant-food-containing compounds in the soil, making them more available to the beet plants. It might also be pointed out that the benefit derived from the application of salt may be a measure of the need of a certain type of fertilization and that if this fertilization were given directly no benefit would be derived from additional application of salt.

CONCLUSIONS

It has been found under widely differing conditions that an application of common salt to the soil for the sugar beet crop has had a beneficial effect upon the yield of roots which is reflected, in many cases, as an increase in calculated sugar production.

The application of salt apparently had a detrimental effect upon the apparent purity coefficient of the juice of the beets. Such applications were found to increase the total amount of ash and to increase the proportion of sodium, chlorine, and possibly potassium in the ash. It is judged, from the known properties of the chlorine and sodium in the ash that any increase in these constituents would interfere in the refining of the sugar and reduce the proportion of the sugar that could be recovered.

There is indication that the amount of potash in the ash of the sugar beet juice may have been greater where salt had been applied than where no salt had been applied or where a potash-bearing fertilizer had been used.

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ADAPTATION OF THE HYDROMETER METHOD TO AGGREGATE ANALYSIS OF SOILS[1]

R. W. GERDEL[2]

THE emphasis that has been placed upon soil aggregation as a significant factor in erosion control indicates the importance of developing suitable methods for studying this physical property of the soil. Among the methods in use for the determination of aggregate-size distribution and the natural structure of soils is the elutriation method used by Baver and associates (1, 2),[3] the wet-sieve method used by Yoder (7), the sedimentation tube of Cole and Edlefsen (6), and the combination wet-sieve and hydrometer method proposed by Bouyoucos (3).

All of these methods are time consuming and limit the number of samples on which analyses may be made. Furthermore, although any of these methods will determine the aggregate-size distribution, none of them will determine the stability of these aggregates. Observations on the residual soils of southeastern Ohio indicate that aggregate stability may be as important as the amount or size-distribution of soil aggregates in any soil erosion investigation.

A method involving the use of the Bouyoucos hydrometer has been developed which permits the determination of certain properties of the soil aggregates. These properties are: (a) The percentage of clay in the aggregated state; (b) the energy required to obtain complete dispersion of the aggregates, or inversely the stability of the aggregates; (c) the dispersibility of the aggregated clay as a result of the application of increasing amounts of mechanical, or chemical and mechanical, energy; and (d) the proportion of the total silt and clay contained in aggregates greater than 0.05 mm.

This method can also be used to determine whether sheet erosion is taking place in the form of texture separates or as aggregates as reported by Yoder (7).

METHOD

A series of 50-gram aliquots are weighed out from each soil sample and permitted to slake under water for at least 30 minutes. On one aliquot the particle-size distribution is determined by the regular Bouyoucos method (4). Successive aliquots receive 2, 4, 6, 8, and 10 minutes' stirring in the Bouyoucos electric mixer without the addition of any dispersion reagent. If 10 minutes of stirring without the use of dispersing agents does not yield a reading of clay as large as that of the chemically dispersed aliquots, then a series of aliquots receiving a total of 2, 4, 6, or 8 cc of the dispersion reagents are each stirred for 10 minutes. The dispersing solutions, sodium silicate and sodium oxalate, are added in equal amounts. Some one of these treatments will result in complete dispersion of the aggregates.

Another aliquot is transferred to the hydrometer cylinder after slaking and is gently shaken for 2 minutes.

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[3]Figures in parenthesis refer to "Literature Cited", p. 110.

Although it has been found that considerable variation in the amount of shaking may not have any appreciable effect upon the aggregated particles—a phenomenon also reported by Bouyoucos (5)—it appears advisable to treat all samples similarly. Satisfactory results have been obtained by inverting the cylinder at 5-second intervals for 1½ minutes, and then at 1-second interval for 30 seconds. Hydrometer readings are then made at 40 seconds and at 1 hour.

CALCULATION AND INTERPRETATION OF DATA

Table 1 and Fig. 1 show how the data can be employed to calculate some values pertinent to the physical properties of the soil and the susceptibility to erosion.

The differences in the erosive characteristics of the two soils, Belmont silty clay loam and Muskingum silt loam, as observed in the field are substantiated by the aggregate stability curves in Fig. 1. Under intensive cropping, Belmont silty clay loam becomes severely gullied and large areas of this soil have been almost totally destroyed for further agricultural use. Muskingum silt loam, however, is more subject to very severe sheet erosion under intensive cultivation, and gullies of sufficient depth to prevent the use of tillage implements are not as common as on the Belmont soil.

TABLE 1.—*Amount and stability of aggregated clay, Muskingum silt loam.*

Treatment		Distribution*			Dispersed clay %
Stirring, min.	Reagent, cc	Sand %	Silt %	Clay %	
10	10	19.8	55.8	24.4	100
10	2	—	—	24.4	100
10	0	—	—	23.3	95.5
8	0	—	—	20.3	83.2
6	0	—	—	20.3	83.2
4	0	—	—	19.3	79.1
2	0	—	—	18.3	75.0
Shake		64.5	29.4	6.1	25.0

*Divisions used by Bouyoucos: Sand, 1.0–0.05 mm; silt, 0.05–0.005 mm; clay, 0.005–0.000 mm

Amount of total clay in water-stable aggregate form $= 100 - \left[\frac{6.1}{24.4} \times 100\right] = 75.0\%$

Amount of total silt and clay in water-stable aggregates greater than 0.05 mm =

$$\left[\frac{64.5 - 19.8}{55.8 + 24.4}\right] \times 100 = 55.7\%$$

Aggregate stability = 10 min. + 2 cc dispersing reagent, expressed as 10 + 2, or 60% based on Bouyoucos' method = 100%.

The percentage of dispersed clay for each energy interval is calculated on a basis of 100% for the clay found in the completely dispersed aliquot. In Table 1, 24.4% of the soil sample was found to be clay (0.005–0.000 mm). The aliquot receiving 6 minutes' stirring contained 20.3% of dispersed clay, hence $\frac{20.3}{24.4} = 83.2\%$ of the total clay content was dispersed by this amount of energy.

The percentage of the total clay content of the soil which is incorporated in water-stable aggregates is determined by dividing the amount of dispersed clay found in the sample which received only shaking by the amount of clay obtained on complete dispersion, and subtracting from 100.

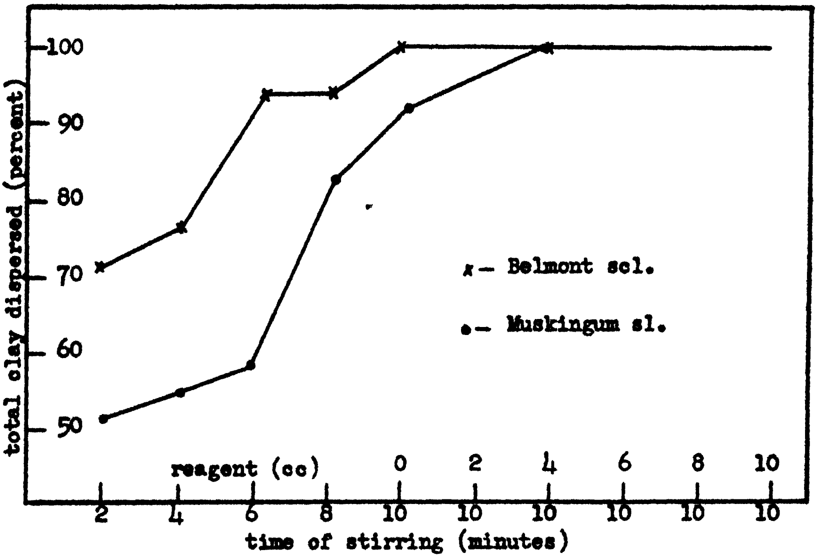

FIG. 1.—Aggregate stability of two residual soils.

The percentage of the total silt and clay contained in water-stable aggregates greater than 0.05 mm is determined by subtracting the sand obtained by complete dispersion from the value obtained for the same size particles by shaking, and dividing by the total silt and clay obtained by complete dispersion.

Since the ultimate stability of the water-stable aggregates is a function of the energy required to obtain complete dispersion of these aggregates, it is possible to compute a numerical value for this stability. The energy value of the Bouyoucos method, prescribing a period of 10 minutes' stirring and the addition of 10 cc dispersion reagents, is taken as an arbitrary maximum of 100%. The actual energy requirements to obtain complete dispersion are then expressed as a percentage of this maximum. If 8 minutes of stirring results in complete dispersion, then $\frac{8}{10 + 10} = 40\%$ aggregate stability; 10 minutes stirring and 2 cc of reagent would produce aggregate stability of $\frac{10 + 2}{10 + 10}$, or 60%.

A slight modification of the method is required where sufficient free electrolytes are present to cause flocculation. The minimum amount of the dispersion reagents required to produce suspension is first determined by adding successive 2-cc portions of dispersion reagents

to an aliquot which has been stirred for 6 or 8 minutes. This minimum amount of reagent required to prevent flocculation is added to each cylinder after stirring is completed. If complete dispersion is not obtained by this means, successive aliquots receive increasing amounts of the reagents before they are stirred for 10 minutes. It has been found that 1 cc of sodium oxalate and 1 cc of sodium silicate are usually sufficient to prevent flocculation.

Interesting data have been obtained by using this method of studying aggregates on different soil types and land use. These data will be reported in a paper now in preparation.

SUMMARY

A method that employs the Bouyoucos hydrometer for studying water-stable aggregates and aggregate stability is presented. Although this method will not determine the complete aggregate-size distribution, it does permit the study of other properties of water-stable aggregates that are pertinent to studies of erosion control and other problems in soil physics.

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COMPARISON OF LEGUME GROWTH IN DIFFERENT SOIL TYPES AT VARYING ACIDITY LEVELS[1]

H. L. HYLAND[2]

THE use of legumes for maintaining soil fertility is generally accepted as being of considerable importance, although their use on acid soils has been somewhat limited due to the lack of adaptability of the more commonly used species to such conditions. Wheeler's (7)[3] early study of plants tolerant to soils with low acidity readings and Coville's (1) emphasis on the need for legumes capable of thriving under such conditions have been partially responsible for the development of interest in "acid-tolerant" legumes. Although it is known that certain legumes are acid-tolerant, specific information is lacking on the response of the different species in respect to their tolerance to acid soils, indicated as such by relatively low pH readings.

The studies herein reported were conducted under greenhouse conditions at Arlington Experiment Farm, Arlington, Va., in 1934 and 1936 to determine the variation in growth response of specific legumes when grown in different soil types and at varying pH levels.

MATERIALS AND PROCEDURE

Korean lespedeza (*Lespedeza stipulacea*), sericea (*Lespedeza sericea*), crown vetch (*Coronilla varia*), and zigzag clover (*Trifolium medium*) were chosen for use in this experiment because of their ability to grow on poor unlimed soils when compared to red clover (*Trifolium pratense*) and sweet clover (*Melilotus alba*). Seedings of crown vetch, sericea, and zigzag clover in quadruplicate were made on December 18, 1933, and red clover and sweetclover on January 23, 1934, for the 1934 experiment. In 1936 all seedings were made on March 11 in triplicate.

One-gallon stone jars equipped with drains in 1934 and without in 1936 were used as soil containers. Artificial cultures were used in all cases for inoculating the seed. Subsequent thinning after germination reduced the number of plants per jar to 7 and 13 for the two years, respectively. All jars were arranged at random on the greenhouse bench.

Jars were weighed at frequent evenly spaced intervals and distilled water added to insure proper moisture conditions for optimum growth. Detailed records on growth and all changes in plant appearance were noted. The experiments terminated October 1, 1934, and June 30, 1936, respectively, at which time final growth notes and soil pH readings were taken.

Bladen fine silt loam with an original pH reading of 4.4 was used in 1934, and Ashe stony loam, DeKalb sandy clay loam, and Clement silt loam with original readings of 4.4, 4.8, and 5.1, respectively, were used in 1936. The pH levels of these soils were raised by adding calcium carbonate to the original soil. The "trial

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[3]Figures in parenthesis refer to "Literature Cited", p. 121.

and error" method was used to determine the proper proportions of calcium and soil necessary for readings of approximately 1 and 2 pH above those of the original soils. The readings were made with a quinhydrone electrode as outlined by Snyder (6).

EXPERIMENTAL RESULTS

Growth differences among the five legumes at progressive dates in 1934 on Bladen fine silt loam and changes in soil pH are shown in Table 1. Variations in growth, first noticeable three to four weeks after planting, are quite evident. In all instances the largest amount and healthiest growth, as judged by consistent gains in height and amount of top and root growth, and the best development of nodules occurred in the pH 5.3 series.

The only appreciable amount of growth in the original soil with a pH of 4.40 was made by sericea and zigzag clover, although red clover made a good start. All the sericea plants remained alive at this pH level until the end of the experiment and the growth nearly equalled that of plants grown at pH 5.30. Zigzag clover showed similar results although a few plants were lost. Considerable trouble was experienced at pH 4.40 with early dying of crown vetch seedlings, necessitating frequent transplanting of healthy seedlings from another source during the first few days after germination, and even these gradually succumbed. Sweet clover plants failed entirely. The number of zigzag clover plants that survived at the 6.40 pH level was three to four times greater than for the other legumes.

The apparent decrease in height of crown vetch at pH of 4.40 and 6.40, and of the zigzag clover plants at 6.40 between January 22 and March 26 is accounted for by the method of measurement. Measurements were made from the base of the stem at the soil surface to the growing tips of the primary leaves. As the seedlings started to die, the primary leaves dropped from the plants and measurements were made to the point of emergence of new growth which was closer to the soil surface than were the tips of the primary leaves. More plants were found dying as the dates of measurement progressed, thus producing a lower average height figure.

After six weeks this dying of plants in the 6.40 series became very apparent. A condition resembling a salt accumulation appeared on the soil surface and upon re-checking the pH reading, it was discovered that through error (limitation of use of the quinhydrode electrode) a large excess of carbonate had been added to the original soil. Between March 26 and April 20, the few plants of all species remaining alive showed an increase in average height, such behavior suggesting that some of the excess carbonate may have been removed through drainage. Midgley (2) has shown that such action occurs.

Between December 1933 and October 1934 the pH readings in the original soil and in that raised to pH 5.30 declined in every case, but an increase of over 1 pH in soils raised to pH 6.40 was shown. This latter change indicates that a large excess of lime was added when originally preparing the pH 6.40 soil.

Results more interesting than those in 1934 were secured in the 1936 tests where Ashe, DeKalb, and Clement soils were used. Growth

TABLE 1.—*Differences in plant growth at three pH levels on Bladen fine silty loam for legumes grown in the greenhouse at Arlington Farm, Va., 1934.**

Soil pH readings		Average height of top growth, cm.						Plant condition Oct. 1, 1934			
Dec. 1933	Oct. 1934	Jan. 22	Feb. 5	Feb. 19	Mar. 5	Mar. 26	Apr. 20	No. live plants†	Av. height tops, in.	Av. length roots, in.	Nodulation
						Crown Vetch					
4.40	4.30	1.48	1.40	1.40	1.23	1.05	1.00	None	—	—	—
5.30	4.81	2.59	2.60	2.15	2.86	5.91	12.40	4.5	20–28	14–24	Good
6.40	7.51	3.21	3.00	2.32	1.87	1.74	3.20	0.8	2–3	Trace	—
						Sericea					
4.40	4.13	2.57	3.50	4.10	5.90	12.70	35.50	7.0	42–48	14–18	Good
5.30	4.94	3.05	3.80	5.45	8.84	21.47	49.80	7.0	56–60	18–20	Good
6.40	7.55	2.19	2.40	2.60	2.77	2.97	2.93	1.5	3–5	3–5	Poor
						Zigzag Clover					
4.40	4.15	1.78	1.90	2.00	2.68	4.32	6.90	6.5	6–8	8–16	Poor
5.30	4.90	2.25	2.40	3.00	4.62	8.16	11.10	6.8	16–20	14–20	Fair
6.40	7.52	2.26	1.90	1.90	1.77	1.41	1.90	5.3	8–12	4–10	Fair
						Red Clover‡					
4.40	4.15	—	—	2.10	2.14	3.73	8.40	None	—	—	—
5.30	4.72	—	—	2.75	3.21	8.95	14.70	4.0	10–14	8–10	Poor
6.40	7.50	—	—	2.55	2.32	1.36	3.20	1.0	—	—	—
						Sweet Clover‡					
4.40	4.40	—	—	1.25	1.18	1.07	1.30	None	—	—	—
5.30	4.72	—	—	1.70	1.88	3.55	9.40	5.5	34–36	26–28	Good
6.40	7.37	—	—	2.05	1.69	1.82	4.00	1.3	30–32	26–28	Fair

*Averages for four replicates of crown vetch, sericea, and zigzag clover and two of red clover and sweet clover.
†Seven plants in all jars originally.
‡Planted one month later than crown vetch, sericea, and zigzag clover.

produced in Ashe stony loam was practically negligible regardless of the pH level as shown by the weights of top and root growth in Table 2. Plants of most species made growth for a few days after germination with a slight tendency to do better at the two higher pH levels, but these differences soon disappeared.

The 5 grams of plant material shown for sericea growing at pH 5.44 is the largest amount produced by any species. The figures for Korean lespedeza and sweet clover are similar, most of the weight being supplied by roots. Sericea also shows the highest plant survival at all three pH levels, followed by zigzag clover and Korean lespedeza, although no plants are shown for the latter in the original soil. All sweet clover plants succumbed in the soil with pH 4.40 and in the two limed series where more growth was expected, the number of plants surviving is comparatively small.

The Korean lespedeza, sericea, and zigzag clover plants at the 6.37 pH level lacked green leaf color and many turned yellow, while only zigzag clover lacked green color at pH 5.44. The plants turning yellow dropped their leaves, and either died completely or remained stunted during the entire experiment. The yellowing of these plants might be due to some minor element deficiency. The lack of growth in this soil type is quite evident from the three-months old plants shown in Fig. 1.

In the Ashe stony loam the pH readings in every case were less on June 30 than at the start of the experiment. The greatest change in pH occurred in the jars originally reading pH 6.37.

Differences in amount of growth in DeKalb sandy clay loam at the three pH levels are quite pronounced (Table 2). In spite of very slow germination all species produced excellent growth at the pH 5.95 level and in some instances a fair amount in the 6.72 series, but a complete failure resulted in the original soil at a pH level of 4.40. The number of plants surviving at the two higher levels is similar for the different crops except sericea which shows a perceptible loss.

At pH 4.40 practically every plant in all the crops yellowed and died shortly after germination. At the two higher pH levels small, round, dark spots appeared on all Korean lespedeza and sericea plants particularly on the cotyledon and primary leaves. This condition was most noticeable on the Korean lespedeza plants. As new growth developed, however, only the lower leaves remained affected, and after these had finally fallen the other portions of the plant were more healthy and practically free from the spotted condition. Similar symptoms have been reported as due to potash deficiency (3, 5).

At succeeding later dates, the difference in growth of all crops between the 5.95 and 6.72 levels became greater. Comparison of the three-months old plants of the four crops may be made from Fig. 2. Attention should be called to the normal growth habits of these plants That of sweet clover is fairly well known, seedling plants under favorable conditions making a growth of 2 to 3 feet the first season, with the stems conspicuous and comprising a large portion of the plant weight. Sericea plants may grow to 3 feet in height the first year and produce a higher percentage (by weight) of leaves than sweet clover. Korean lespedeza and zigzag clover, however, possess finer stems and

produce a more spreading and shorter type of growth. Zigzag clover is a more prostrate grower than Korean lespedeza.

The largest amounts of growth were obtained at the 5.95 level. Sweet clover showed the largest combined plant weight with a total of 70.7 grams for stems and roots. Considering the growth habits, zigzag clover with an average of 57.3 grams and Korean lespedeza with 53.4 grams both compare favorably with sweet clover in amount of growth. Sericea shows the smallest total plant weight with 38.4 grams.

FIG. 1.—Comparative growth of three-months old legume plants in three pH levels of Ashe stony loam. From top to bottom, sericea, Korean lespedeza, zigzag clover, and sweet clover.

TABLE 2.—*Differences in plant growth at three pH levels on three acid soil types for legume plants grown in the greenhouse at Arlington Farm, Va., 1936.**

Ashe stony loam					DeKalb sandy clay loam					Clement silt loam				
Soil pH readings		Growth record 6/30			Soil pH readings		Growth record 6/30			Soil pH readings		Growth records 6/30		
May 11	June 30	No. live plants†	Tops, grams‡	Roots, grams‡	May 11	June 30	No. live plants†	Tops, grams‡	Roots, grams‡	May 11	June 30	No. live plants†	Tops, grams‡	Roots, grams‡
							Korean Lespedeza							
4.40	4.29	None	—	—	4.80	4.04	None	—	—	5.10	4.68	13.0	11.3	19.3
5.44	5.12	12.3	1.7	3.0	5.95	5.42	11.7	30.7	22.7	6.13	5.32	13.0	15.3	13.7
6.37	5.69	10.7	1.0	—	6.72	5.88	11.7	17.3	12.3	7.09	6.30	12.7	16.0	12.3
							Sericea							
4.40	4.31	9.7	1.0	0.7	4.80	4.07	None	—	—	5.10	4.69	12.0	10.3	10.3
5.44	4.97	12.3	2.3	2.7	5.95	5.28	8.7	22.7	15.7	6.13	5.30	12.7	12.3	10.7
6.37	5.68	12.3	1.0	—	6.72	5.74	6.0	8.3	6.0	7.09	6.18	11.7	12.0	7.7
							Zigzag Clover							
4.40	4.34	3.3	1.0	—	4.80	4.08	1.0	—	—	5.10	4.73	13.0	5.3	7.3
5.44	5.03	12.3	1.3	0.7	5.95	5.33	12.0	34 3	23.0	6.13	5.39	12.3	11.0	16.7
6.37	5.80	12.3	1.0	—	6.72	5.79	10.3	15.0	8.7	7.09	6.42	12.0	12.3	14.7
							Sweet Clover							
4.40	4.33	None	—	—	4.80	4.05	None	—	—	5.10	4.72	12.7	1.3	2.7
5.44	5.07	4.3	1.0	3.0	5.95	5.44	10.3	20.7	50.0	6.13	5.37	11.3	5.7	11.3
6.37	5.76	4.0	1.0	—	6.72	6.03	10.7	19.7	32.3	7.09	6.52	12.0	8.3	9.7

*Averages for three replications.
†Thirteen plants in all jars originally.
‡Weights are of the green material.

At pH 6.72, sweet clover produced top growth equal to that in the 5.95 pH series, but less root weight. Korean lespedeza and zigzag

Soil pH readings

4.80 5.95 6.72

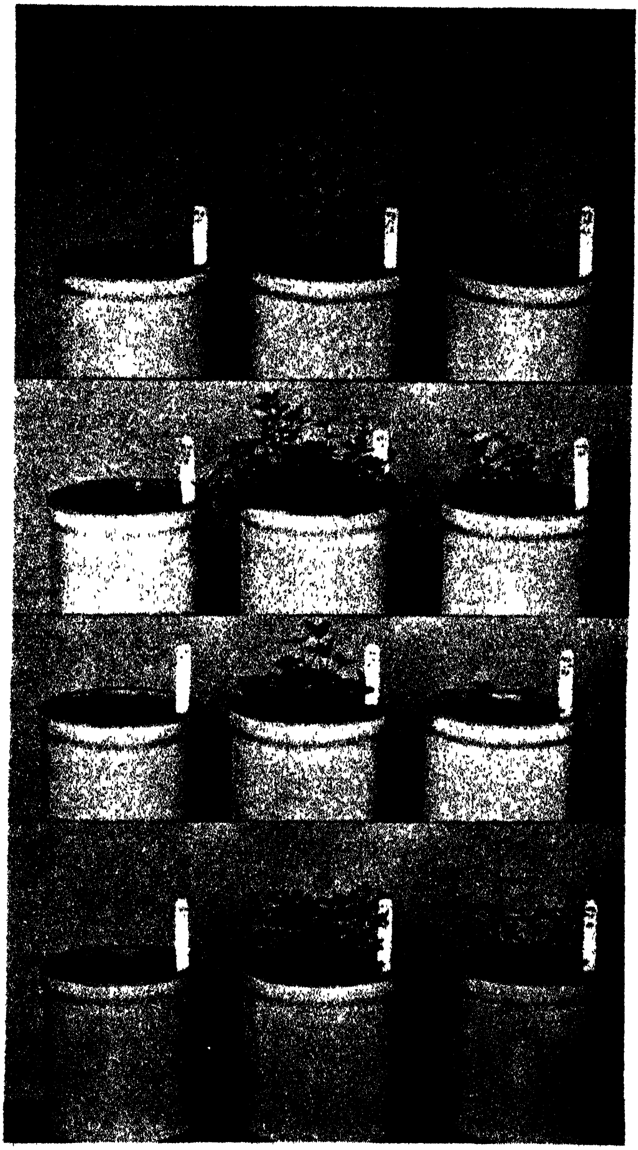

Fig. 2.—Comparative growth of three-months old legume plants in three pH levels of DeKalb sandy clay loam. From top to bottom, sericea, Korean lespedeza, zigzag clover, and sweet clover.

clover with averages of 29.6 and 23.7 grams, respectively, approximated only half the amount of plant material produced at pH 5.95. The growth of sericea compared rather poorly with that of the other crops at the pH 6.72 level, or with the material produced by it at the next lower pH level.

Decreases in pH in the DeKalb soil are least in the soils of the 5.95 pH series or where the most plant growth is shown to have occurred. Changes in the original soil with a pH of 4.80 and in that raised to pH 6.72 were similar, ranging from 0.69 to 0.98 pH.

The uniformity of plant growth in Clement silt loam (Table 2) presents a contrast to that produced in the Bladen, Ashe, and DeKalb soils. The survival of plants is high and similar regardless of the crop or degree of soil acidity. In amount of growth, Korean lespedeza produced the most uniform average weights, showing 30.6, 29.0, and 28.3 grams, respectively, for the three pH levels. Zigzag clover shows 27.7 and 27.0 grams, respectively, for the two higher levels, but produced only 12.6 grams of material in the original soil. Fig. 3 shows the comparative three-months old growth of the four species.

Probably the most interesting observation, as shown in Table 2 and Fig. 3, is that sweet clover produced less material in proportion to its normal growth than the other three legumes. It also produced the poorest growth of all the crops in the original soil, followed closely by zigzag clover.

The average decreases in pH were 0.40, 0.79, and 0.74 for the original soil and two succeeding higher levels, respectively.

Attention is called to the weights of plants in this soil and to that of plants in the DeKalb sandy clay loam at pH 5.95. Since the growth as shown in Figs. 2 and 3 was quite similar, plant weights would also be expected to be similar The lower weights of the plants in the Clement silt loam can be partially accounted for by the fact that red spider infestation was heavy, and by the time final weights were recorded many leaves had been lost.

DISCUSSION

From the data presented, variable and highly significant growth differences have been found to occur, not only among the legume crops tested but also in the four acid soil types used. The conditions under which these differences were found indicate quite definitely that a certain expected amount of growth cannot be correlated with specific soil pH readings. Results show that plant species, soil type, and addition of lime were, in a measure, responsible for growth differences.

Growth responses in the different soil types varied with the crop. The so-called acid-tolerant plants, as a group, were more successful at the lower pH readings than sweet clover, and in some cases produced as much or more material at the higher pH levels. This was particularly true of sericea which made good growth in the original Bladen and Clement soils, while sweet clover made only a fair showing in the latter. Red clover, grown only in the Bladen soil, proved less responsive at each corresponding pH than any of the acid-tolerant plants or sweet clover. Where the plants were grown at readings approximately 1.0 pH higher than the originals, sericea produced

more growth than sweet clover in the Bladen, Ashe, and Clement soils and practically the same amount in DeKalb. In the heavily

Soil pH readings

5.10 6.13 7.09

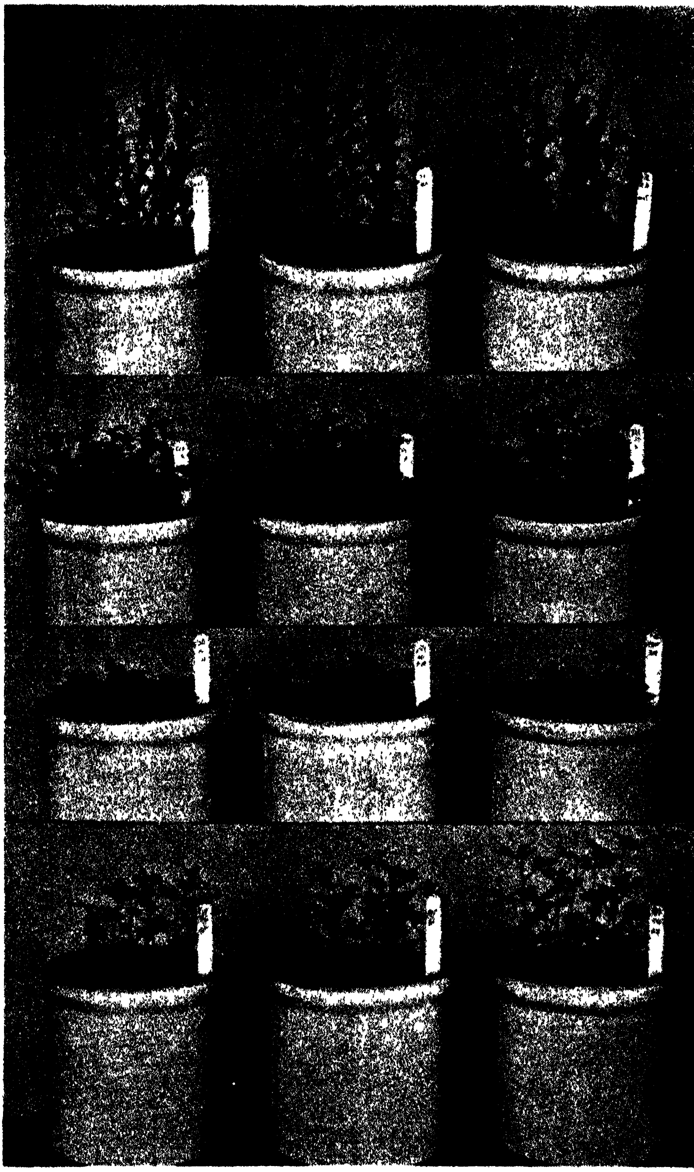

FIG. 3.—Comparative growth of three-months old legume plants in three pH levels of Clement silt loam. From top to bottom, sericea, Korean lespedeza, zigzag clover, and sweet clover.

limed series, however, sweet clover produced the most growth in the Bladen and DeKalb soils.

It is interesting to note that certain variations have occurred in the acid-tolerant group of plants showing differences in possible degree of tolerance. In the unlimed jars, Korean lespedeza, sericea, and zigzag clover plants on the Clement type made relative growth in the order named. Only the latter two were able to produce any semblance of growth in the Bladen and Ashe soils, with sericea showing a little advantage in plant survival and amount of growth. Crown vetch failed in its only trial in the Bladen soil. In the higher pH levels where calcium carbonate had been added, except in Ashe stony loam where practically no growth was made, a few differences were noted in amounts of growth giving the advantage to one species over another in the same pH level.

It appears that the differences in growth noted in the various crops can be accounted for only by the variation in adaptability of these specific legumes to acid soils since they were grown under controlled conditions.

The wide variations in plant growth secured with a difference of only 0.7 pH for the four soils in their original state strongly indicate that factors other than pH affect crop adaptation to acid soils. While some unknown condition unfavorable for plant growth apparently existed in the Ashe soil even at higher pH levels where lime had been added, similar conditions, as measured by plant response, were present in the Bladen and DeKalb soils. The addition of lime to the latter soils produced more favorable plant growth, although the highest pH series produced less growth than the intermediate pH lots. This inhibition of growth may have been due to overliming of acid soils (4).

Plant growth, as correlated with the use of lime to produce the various pH levels, failed to show consistent results. Changing the readings of the Bladen and Ashe soils from 5.30 and 5.44 to the next higher pH, respectively, failed to increase the amount of growth. The same was true in DeKalb, except the growth at the higher pH was good when compared to that of the above two soils. In the Clement soil, however, increasing the alkalinity brought significant growth increases for three of the four species under study.

From these results it would seem that liming to correct acid conditions may not always prove a solution for bettering plant growth, if changes in pH are to be the basis for judging such corrections, and any statement to the effect that certain legumes will grow best in a soil of a specific acid reaction can easily be misleading.

SUMMARY

Korean lespedeza, sericea, zigzag clover, and crown vetch plants, which usually grow well on poor, unlimed soils and red clover and sweet clover plants which are more responsive to limed soils, were grown in four soil types under greenhouse conditions and at three pH levels.

Wide variations in growth of the different crops were found to occur when they were grown in different soil types and at different pH levels.

Sericea was a little more tolerant of lower pH readings than Korean lespedeza or zigzag clover while the latter two compared favorably with each other in this respect. Zigzag clover showed a tendency to tolerate a higher alkaline concentration than sericea. Crown vetch failed to grow in a soil of 4.4 pH and gave only a fair growth in the 5.3 level for the same soil. Considering the amount of growth normally produced, Korean lespedeza, sericea, and zigzag clover in many cases made relatively more growth than either red clover or sweet clover, regardless of pH level.

The addition of calcium carbonate to a soil with an original pH reading of 5.10 did not significantly increase the amount of legume growth.

Soil pH readings, as indicated by the above studies, were not true indicators of the adaptation of different legume crops to such soils.

Decrease in soil pH occurred between the start and finish of the experiments in all soil types and different pH levels of these types, except in the 6.4 series of the Bladen fine silt loam where a large excess of calcium carbonate was added through error. The largest decreases occurred where most plant growth resulted and where the largest amounts of lime had been added.

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EFFECT OF LOCUST TREES UPON THE AVAILABLE MINERAL NUTRIENTS OF THE SOIL[1]

W. H. GARMAN AND F. G. MERKLE[2]

FOR many years the black locust (*Robinia Pseudo-Acacia* L.) has been used in the repair of soils ruined by erosion and mismanagement. Its ability to establish itself on barren subsoils is equaled by but few other plants. Shortly after it is established the site becomes improved to such an extent that other species, in themselves less tolerant to barrenness, are found to thrive. Kentucky bluegrass may be encouraged to grow voluntarily on bare subsoil in association with locust.

Ferguson (1)[3] called attention to the fact that in a catalpa grove adjacent to a locust grove the growth of the catalpas was much better close to the locusts and that it decreased gradually as the distance from the latter increased. He reported, and it was later confirmed by MacIntyre and Jeffries (2) that the nitrogen content of the soil close to the locust grove was higher and that it diminished as the distance increased. Chapman (3) has likewise shown that the growth of catalpa, white ash, tulip poplar, black oak, and chestnut decreased progressively as the distance from the locusts increased. He found that the total nitrogen in the locust grove was 3,900 pounds per acre and only 1,800 pounds outside the influence of the locusts.

In a 25-year-old locust grove in Mason County, Illinois, Gustafson (4) noted in 1934 that the surface of the sand under the locusts was covered with the remains of the locust leaves and some small twigs which had accumulated, and that Kentucky bluegrass (*Poa pratensis*) was well established under the trees, but that it did not gain foothold a short distance away. He attributed the beneficial effect of the trees to the nitrogen and other nutrients, and to better moisture and temperature conditions.

Apparently, quantitative evidence of the nitrogen-accumulating power of the locust has been demonstrated. Its ability to bring available mineral nutrient elements to the surface and to alter the pH value of the soil is not as well known, or at least quantitative data to substantiate this belief are wanting. Of course it is well known that all trees possess this tendency. A measure of the mineral-enrichening function of locusts is reported herewith.

About seven years ago a steep barren road embankment, cut into what is known as the Morrison soil, was planted to locust saplings. This soil, although underlain at considerable depth by dolomitic sandstones is very acid throughout its A and B horizons and the greater part of its C horizon. The B horizon contains a ferruginous clay. Under natural conditions the surface soil grows no bluegrass

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[3]Figures in parenthesis refer to "Literature Cited", p. 124.

while the subsoil is the last place one would look for this species. However, it was noted that, after the locust saplings had dropped three or four crops of leaves, bluegrass began to grow spontaneously near the base of the trees where the leaves lodged. In a few years a circular area around each tree trunk about 8 to 18 inches in diameter was covered with feathery locust leaves and spears of bluegrass. It seemed possible that not only the nitrogen fixed by the locusts, but also the available mineral nutrients brought to the surface by the leaves might help explain the volunteer appearance of bluegrass on such an unfavorable site.

To determine if mineral enrichment had taken place, samples were taken, one from within the litter circle and one from the barren embankment a short distance from the trees but where no leaves had collected. In each case the surface leaves and soil were removed and the actual samples taken between the second and fifth inch in depth. Thus no leaf debris was included. Five paired samples were taken at average distances of 3½ to 4 feet from each other. The samples were quickly dried and analyzed for pH value and for readily available calcium, magnesium, potassium, and phosphate. The latter were extracted with N/4 sodium acetate made to pH 5 and determined by the micro methods. Total nitrogen was not determined as this property had been investigated by other workers. The results are reported as pounds in 2 million pounds of dry soil. The data are presented in Table 1.

TABLE 1.—*Readily extractable mineral nutrients in soil as influenced by locust litter.**

Lab. No.	Comparison	Ca	Mg	K	PO_4	NO_3	pH
2803	Under litter	976	74	150	Trace	30	7.1
2802	Outside	432	60	50	Trace	10	5.4
2998	Under litter	936	84	200	Trace	Trace	7.2
2999	Outside	340	31	100	Trace	Trace	6.3
3000	Under litter	720	101	200	Trace	10	6.6
3001	Outside	208	50	100	Trace	Trace	5.2
3002	Under litter	792	134	150	Trace	10	6.6
3003	Outside	180	55	100	Trace	Trace	5.1
3004	Under litter	888	120	150	Trace	30	5.6
3005	Outside	340	140	100	Trace	Trace	5.0

*Expressed as pounds in 2 million pounds of dry soil.

The findings are very conclusive. Basic nutrients have been withdrawn from the lower layers and deposited at the surface. The amounts of active calcium, magnesium, and potassium have been significantly increased as a result of the deposition of leaves. The pH value of this subsoil is normally 5.0 to 5.5. The effect of the litter has been to raise the value to close to the neutral point.

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RECENT STUDIES ON THE GENETICS OF THE SOYBEAN[1]

C. M. Woodworth and L. F. Williams[2]

In connection with the investigational work on soybeans being carried on at the Illinois Agricultural Experiment Station in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the genetics of the soybean occupies a prominent place. Because of the growing interest in this new crop, particularly from the breeding standpoint, it has seemed desirable to present briefly the results of recent genetic studies. This account is divided into two parts, namely, (a) a description of new chlorophyll-deficient types, together with any available data on mode of inheritance, and (b) a discussion of new linkage relationships.

NEW CHLOROPHYLL-DEFICIENT TYPES

The y_4 type is a yellowish-green type found in F. P. I. 65388, a small-seeded brown bean obtained from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. The original lot of seed was treated with radium by Doctor J. T. Buchholz, Botany Department, University of Illinois. The mutant appeared in the progeny of a plant grown from one of these treated seeds. The ratio was 22 normal to 3 yellow. Fifteen of the normal green plants were tested in the greenhouse. Of these, 4 bred true for green and 11 segregated in approximately a 3:1 ratio. The evidence seems clear, therefore, that the mutant is a simple recessive to the normal.

The y_5 type is a greenish-yellow type first observed as a mutant in the Wilson V variety. It bred true from the first. A cross was made with the Virginia variety. Two F_1 plants were produced, both normal green. Of 104 F_2 plants, 80 were normal, 24 greenish-yellow. In the F_3 generation, of 36 families grown, 12 bred true for green and 24 segregated in a 3:1 ratio.

Both y_4 and y_5 are weak, although y_5 is the better of the two. They are easily distinguished from each other in appearance. The chlorophyll of y_4 is uniformly reduced, so that the leaf surface has a uniform appearance, while in y_5 there are areas in the leaf of varying chlorophyll intensities. The leaf seems to change from yellow to green and back again as it is turned at various angles to the sun.

In the cross between y_5 and Virginia, two other pairs of genes were involved, namely, Tt (tawny vs. gray pubescence) and R_1r_1 (black vs. brown coat color). The results given in Table 1 indicate independence between these and Y_5y_5.

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[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill., in cooperation with the U. S. Regional Soybean Industrial Products Laboratory, U. S. Dept. of Agriculture. Published with the approval of the Director of the Experiment Station. Received for publication November 19, 1937.

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TABLE 1.—*Data showing independent inheritance between Y_5y_5 and Tt and between Y_5y_5 and R_1r_1.*

	Pubescence color and leaf color				
F_2 classes	TY_5	Ty_5	tY_5	ty_5	Total
Actual results	33	5	18	2	58
Expected results (9:3:3:1)	32	11	11	4	58

	Coat color and leaf color				
F_2 classses	R_1Y_5	R_1y_5	r_1Y_5	r_1y_5	Total
Actual results	43	9	6	1	59
Expected results (9:3:3:1)	33	11	11	4	59

Deviations from expected results in Table 1 are due mainly to deficiency of the y_5 segregates.

The y_4 and y_5 types were crossed and produced normal green F_1 plants. Incidentally, much hybrid vigor was apparent in this cross. The F_2 generation segregated in a 9:7 ratio of normal to chlorophyll-deficient plants. Of 186 plants, 112 were green and 74 yellowish. On the basis of a 9:7 ratio, 105 green and 81 yellow would be expected, a deviation of 7 from expectation. From this cross a third type of chlorophyll abnormality is expected, namely, that which is recessive for both y_4 and y_5. However, on account of the low vigor and sparse seed production of the chlorophyll-deficient segregates, the double recessive could not be distinguished from the y_4 and y_5 types. Since very little seed was obtained from these segregates, progeny tests could not be made. It is hoped that further work with the heterozygous normal segregates will bring about the isolation of the double recessive type.

The y_6 type is a pale green type found in the Rokusun variety of vegetable soybeans. It can be easily distinguished from the normal green in the early plant stage, but later it apparently develops more chlorophyll and to all outward appearance is normal green. It appears to be a simple recessive to the normal. A cross between y_6 and Illinois Type 24A gave 76 green to 20 pale green. Although the pale class is somewhat deficient, this is evidently a monohybrid segregation. The y_6 type was discovered only this past season and no crosses have yet been made with other chlorophyll-deficient types.

The y_7 type is characterized by a distinct yellowing which extends to the leaves, stems, and pods as well as the seeds. The yellowing is first noticeable in the stems and then the leaves, pods, and seeds become progressively yellow. On the leaves it shows first in the veins and these yellow-veined leaves serve to distinguish it readily from other yellow types. This gene has more of a yellowing effect than any other so far discovered, as it affects even the seed coat and cotyledons. In spite of the very pronounced reduction of chlorophyll, this type is fairly vigorous. It was observed in a few vegetable soybeans, but more commonly in F. P. I. 81029. It has not been tested in controlled crosses, but in families segregating naturally it occurs in ap-

proximately 1 out of 4 plants. One such ratio of 13 green to 3 yellow indicates that it is probably due to a single gene.

The y_8 type is a chlorophyll-deficient type characterized by yellow-green leaves in the young plant. As the plant develops the leaves become more greenish and the newer leaves formed show the deficiency less and less until the plant cannot be distinguished from the normal green. There seems to be some reduction in vigor though very little. The y_8 type has not been tested in crosses as yet and there are no segregating progenies available from which an idea of its inheritance can be gained.

NEW LINKAGE RELATIONSHIPS

Pubescence color, gene pair Tt, is assumed to be in chromosome I. A cross between the Elton variety and a variegated leaf type (v_1) showed evidence of linkage between pubescence color and cotyledon color, repulsion phase. The data are given in Table 2.

TABLE 2.—*Data showing linkage between pubescence color and cotyledon color.*

F_2 classes	Tawny pubescence		Gray pubescence		Total
	Yellow cotyledon	Green cotyledon	Yellow cotyledon	Green cotyledon	
Actual results	99	11	51	1	162
Expected results (45:3:15:1)	114	7.5	38	2.5	162
Expected results (13% crossing over)	112	10	40	0	162

The previously mentioned cross also segregated for green vs. yellow seed coat color. This character was formerly found by Woodworth (4)[3] to be linked to one of the duplicate cotyledon factors, arbitrarily designated d_1, with about 13% crossing over. The linkage relationship was again confirmed by the results of this cross (Table 3).

TABLE 3.—*Data showing linkage between green vs. yellow seed coat color and yellow vs. green cotyledon color.*

F_2 classes	Green seed coat		Yellow seed coat		Total
	Yellow cotyledon	Green cotyledon	Yellow cotyledon	Green cotyledon	
Actual results......	101	12	48	0	161
Expected results (45:3:15:1)......	113	7.5	38	2.5	161
Expected results (13% crossing over)	111	10	40	0	161

Pubescence color and coat color (green vs. yellow) showed random assortment as indicated in the segregation ratios given in Table 4.

Since therefore, genes t and g are independent and located on different chromosomes, and since g is arbitrarily assumed to be linked

[3]Figures in parenthesis refer to "Literature Cited", p. 129.

TABLE 4.—*Data showing independence between pubescence color and coat color.*

F_2 classes	TG	Tg	tG	tg	Total
Actual results.....	87	29	27	18	161
Expected results (9:3:3:1).....	91	30	30	10	161

with d_1, then t may be considered to be linked with d_2. Hence, in the revised soybean chromosome map, d_2 is added to chromosome I, and located 13 units from t. It has not yet been determined, however, whether d_2 is just 7 units from *e*, as is indicated on the revised map, and since *e* stock has been lost, it will be impossible to determine this point.

Evidence for a fourth group of linked genes was obtained from three crosses which involved genes p_2 (glabrousness) and de_2 (defective seed coat). The data are given in Table 5.

TABLE 5.—*Data showing linkage between glabrousness and defective seed coat (coupling phase).*

Cross No.	F_2 classes				Crossing over
	P_2De_2	P_2de_2	p_2De_2	p_2de_2	
44........	97	3	1	8	2.0+
104........	27	0	0	3	0.0
151...........	72	0	0	18	0.0
Total .	196	3	1	29	

These genes are, therefore, assumed to be located on chromosome IV about 2 units apart. This type of defective coat is different from that reported by Stewart and Wentz (2) as linked with pubescence color. It has a net-like appearance, occurs in combination with either tawny or gray pubescence, and on variously colored seed coats.

Formerly genes p_1 and r_1 were located on chromosome II, 12 units apart, and P_1 18 units from M. However, from this information it could not be determined whether the gene order was p_1-r_1-m or r_1-p_1-m. Knowledge of the relationship between r_1 and m was needed to settle this point. In a cross between F. P. I. 91073 and F. P. I. 84896, gene pairs $r_1r_1^0$ (brown coat vs. reddish brown coat) and Mm (mottling vs. self-color) were involved in the coupling phase. The F_2 ratios are given in Table 6.

TABLE 6.—*Data showing linkage between gene pairs $r_1r_1^0$ and Mm.*

F_2 classes	Mr_1	Mr_1^0	mr_1	mr_1^0	Total
Actual results....	60	11	10	11	92
Expected ratio (no linkage)........	9	3	3	1	16
Expected results (no linkage).........	52	17	17	6	92
Expected results (30% crossing over)	57	12	12	11	92

Owen (1) made the observation that there should be linkage between these gene pairs, but his numbers were too small to indicate any. In certain cases where the crossing over percentage is as high as 30, the data might indicate independent inheritance.

In the light of these data, then, the gene order in chromosome II is established as r_1-p_1-m as indicated on the provisional map (Fig. 1).

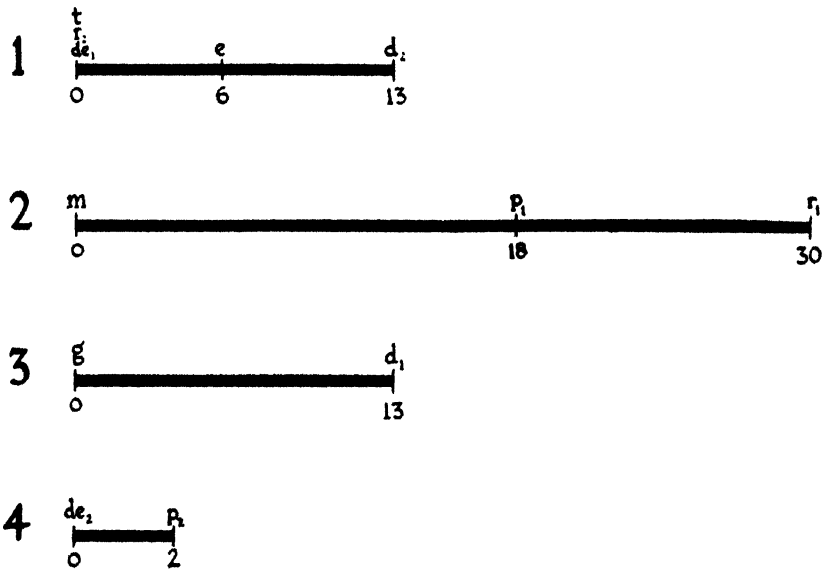

FIG. 1.—Provisional soybean chromosome map.

Other gene pairs have shown relationships in inheritance. Takahashi (3) reports a linkage between leaf shape and number of seeds per pod, with a cross-over percentage of about 10. This may constitute a fifth chromosome group. We have also observed this relationship but have not been able so far to determine the strength of linkage. Also, we have noted a tendency for f (fasciation) to be associated with late maturity. The evidence indicates that f may be located on chromosome I.

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A STUDY OF THE TIME OF PASTURING ALFALFA[1]

H. C. Rather and A. B. Dorrance[2]

In previous studies of alfalfa used for pasture which the authors have made in Michigan,[3] grazing was discontinued by September 1 to give the plants opportunity to store root reserves before winter. On the basis of other work at this station indicating that the clipping of alfalfa during September was particularly injurious,[4] it was assumed that close grazing would likewise prove detrimental.

In 1936, a time-of-grazing experiment was started to gain additional information on the influence of fall grazing on the alfalfa and to determine the time in the spring when grazing could be started safely. The experiment was conducted on Bellefontaine sandy loam soil limed for the correction of acidity and seedings were made in 1935, at which time 250 pounds per acre of 0–8–24 fertilizer were applied. Hardigan alfalfa was seeded in oats and good stands were secured.

The grazing methods here reported were carried on in 1-acre paddocks, each time-of-grazing treatment being run in triplicate. The grazing practices followed were (a) pastured from April 30 to August 28; (b) pastured May 14 to August 28; and (c) pastured May 14 to October 16.

May, June, July, and early August were unusually dry, precipitation during this period being only 5.89 inches, about 50% of normal. From August 18 to October 10, 12.26 inches of rain fell at this station, about twice the normal. From July 7 to July 15, the maximum temperature each day exceeded 100° F, a record heat wave for this locality. In general, all paddocks were pastured off completely by August 28. New growth was stimulated by the late August and September rains. All alfalfa made an excellent recovery and that pastured throughout September and the first half of October furnished good grazing for eight spring lambs per acre, each of which made good gains during this period. The results are presented in Table 1.

It is not intended, at this early stage in the experiment, to draw definite conclusions concerning livestock returns from the different grazing treatments. This is particularly true in dealing with any comparison between grazing April 30 to August 28 and May 14 to August 28. For the present, these returns must be considered com-

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[3]Rather, H. C., and Dorrance, A. B. Pasturing alfalfa in Michigan. Jour. Amer. Soc. Agron., 27:57–65. 1935.

[4]Silkett, Val W., Megee, C. R., and Rather, H. C. The effect of late summer and early fall cutting on crown bud formation and winter hardiness of alfalfa. Jour. Amer. Soc. Agron., 29:53–62. 1937.

TABLE 1.—*Grazing returns from alfalfa under different time-of-grazing treatments, W. K. Kellogg Farm of Michigan State College, 1936.**

Grazing period	Treatment and grazing returns								
	Pastured Apr. 30–Aug. 28			Pastured May 14–Aug. 28			Pastured May 14–Oct. 16		
	Sheep-days pasture	Gains, lbs. per acre	Gains, lbs. per sheep-day	Sheep-days pasture	Gains, lbs. per acre	Gains, lbs. per sheep-day	Sheep-days pasture	Gains, lbs. per acre	Gains, lbs. per sheep-day
Apr. 30–May 14...	149	109.7	0.736	—	—	—	—	—	—
May 14–May 28 ..	88	61.9	0.703	236	219.9	0.932	215	162.0	0.753
May 28–June 25 ..	93	57.3	0.616	140	53.0	0.379	97	33.5	0.345
June 25–July 23. ..	112	33.0	0.295	150	23.0	0.153	154	59.7	0.388
July 23–Aug. 28.. .	131	8.6	0.066	75	−3.3	0.044	152	−11.6	0.076
Aug. 31–Oct. 16..	—	—	—	—	—	—	184	125.7	0.683
Total ...	573	270.5	—	601	292.6	—	802	369.3	—
Average gain in lbs. per sheep-day ..			0.472			0.486			0.460

*The figures represent average acre returns from three 1-acre paddocks used for each treatment. One of the paddocks in the April 30 to August 28 treatment and one in the May 14 to October 16 treatment were on land previously infested with downy brome grass (*Bromus tectorum*) and this weed was present in appreciable quantities in these two paddocks. Grazing returns from them were comparable to those from the non-infested paddocks and are included in this report, but the presence of the downy brome grass may influence the alfalfa adversely in the future.

parable. Neither was there any noticeable difference in the final behavior of the alfalfa under these two treatments. In both cases, excellent fall recovery was made and the alfalfa survived the winter in fine condition and made a vigorous growth in the season of 1937.

The purpose of the present report is to point out that the three paddocks pastured from May 14 to October 16 were very severely injured by the fall grazing. In treatment, this series differed from the one pastured May 14 to August 28 only by the grazing of eight lambs per acre from August 31 to October 16. The lambs averaged 61½ pounds each on August 31 and 77.3 pounds each on October 16. In calculating sheep-days pasture, two lambs were considered th equivalent of one mature sheep.

During the six weeks in September and October that lambs were on this pasture, they kept the alfalfa short and consequently, during this critical fall period, the alfalfa had no opportunity to store an adequate supply of reserve food.

In late October, and again in late November, root samples of alfalfa were dug from the three grazing treatments and root weight, percentage dry matter, and laboratory winterhardiness determinations were made. Winterhardiness was measured by means of electri-

cal conductivity as described by Dexter, *et al.*[5] The results of these determinations are presented in Tables 2 and 3.

TABLE 2.—*Comparative influence of time-of-grazing alfalfa on root and crown bud development in the fall.**

Grazing period	Green weight of 100 roots (upper 5 inches), grams	Dry Matter %	Dry weight of 100 roots, grams	No. crown buds on 100 roots	Green weight of crown buds, grams	Dry weight of crown buds, grams
	Alfalfa Sampled Oct. 30, 1936					
Apr. 30 to Aug. 28....	344	39.80	137	1002	71.10	7.30
May 14 to Aug. 28.	353	38.44	136	1068	79.06	8.01
May 14 to Oct. 16....	209	32.28	67	172	7.43	1.45
	Alfalfa Sampled Nov. 28, 1936					
Apr. 30 to Aug. 28....	312	33.60	105	1624	85.20	16.28
May 14 to Aug. 28 . .	298	34.74	104	1704	113.66	30.56
May 14 to Oct. 16....	190	31.35	60	900	31.02	3.42

*Determinations reported in Tables 2 and 3 were made by S. T. Dexter, Farm Crops Section, Michigan Experiment Station.

TABLE 3.—*Comparative influence of time-of-grazing alfalfa on winterhardiness of the plants as indicated by electrical conductivity determinations.*

Grazing period	Specific conductivity* x 10^7	
	Sampled Oct. 30	Sampled Nov. 28
April 30 to August 28...	1,976	1,882
May 14 to August 28	1,749	2,268
May 14 to October 16.....	1,933	2,833

*All conductivity figures represent the average of three determinations.

The data in Table 2 indicate an adverse response of the alfalfa plants to close fall grazing. The roots of the alfalfa not pastured in the fall were not only heavier but higher in percentage dry matter. The opportunity for fall storage of root reserves was associated with the development of larger, more vigorous, and a great many more crown buds.

As indicated by the electrical conductivity determinations, hardening of the alfalfa was not far advanced when the first samples were dug October 30, but a month later the alfalfa from the two series not grazed in the fall was in a materially more hardened condition than that pastured during September and October.

[5]DEXTER, S. T., TOTTINGHAM, W. E., and GRABER, L. F. Investigation of hardiness of plants by measure of electrical conductivity. Plant Phys., 7:63–78. 1932.

The final indication of the adverse influence of the fall grazing was the way in which the alfalfa survived the open winter of 1936–37. General observations throughout this section of Michigan indicated winterkilling of both wheat and alfalfa to be somewhat more prevalent than usual. However, no winterkilling of alfalfa was apparent in any of the paddocks in which grazing was discontinued August 28, regardless of treatment earlier in the season.

The three paddocks grazed August 31 to October 16 presented a vastly different picture. The well-drained sandy loam soil on which these trials were conducted is not one on which heaving is usually a serious problem. Yet, when these paddocks were observed in late March, more than 90% of the alfalfa plants had been so weakened by freezing injury that they were heaved 2 to 4 inches out of the ground. In two of the three paddocks, most of these heaved plants were dead and when growth started in late April, only a very small percentage of the plants were alive. The plants which survived tended to be in patches that were possibly grazed less severely in the fall than the balance of the field. The alfalfa stand in these two paddocks could properly be described as ruined for all further use either for grazing or for hay.

The third paddock was somewhat lower and possibly in a little better state of fertility, and, although heaving of the plants was almost universal, the mortality was not so great. A fair stand of alfalfa, slower to start and lacking in vigor still remained the following spring. This was the only paddock of the three to have enough alfalfa to warrant continuation of grazing in the season of 1937.

Although it is possible that, during a more favorable winter, the actual killing of fall-grazed alfalfa might not be so general as it was in the trials here reported, the alfalfa on which grazing was discontinued August 28 came through the winter in excellent condition and that pastured closely in September and October was injured so severely that it appears worthwhile to report this phase of the experiment at this time.

SUMMARY

Alfalfa was pastured April 30 to August 28, May 14 to August 28, and May 14 to October 16, each grazing treatment being carried on in three 1-acre paddocks.

Grazing returns as indicated by sheep-days pasture and gains per acre were comparable for the three treatments up to August 28, with additional returns secured from that pastured May 14 to October 16 being due entirely to fall grazing.

The alfalfa pastured in the fall had less dry matter per 100 roots and had developed fewer and much less vigorous crown buds when sampled October 30 and November 28.

Electrical conductivity determinations with the alfalfa roots indicated that the alfalfa on which grazing was discontinued August 28 had hardened off much better by November 28 than that pastured in the fall regardless of previous treatment.

Root starvation caused by fall grazing in September and October and heaving of the dead plants during winter and spring was almost

universal in the fall-pastured alfalfa, and in two of the three paddocks the stands left in the spring of 1937 were of little use either as hay or pasture.

The alfalfa not pastured in September and October showed no indications of winter injury, no heaving was apparent, and excellent stands of vigorous alfalfa were available for continuation of pasture in 1937.

INOCULATION OF SESBAN[1]

C. F. BRISCOE AND W. B. ANDREWS[2]

SESBAN has come into agricultural importance as a summer green manuring crop in recent years,[3] but it has no value as a forage crop for stock do not like it. There are two species of sesban given in Small's "Manual of the Southern Flora" and both are native to North America.[4] *Sesban emerus* Aubl. occurs in Alabama, Georgia, Florida, New Mexico, the West Indies, and Central America; while *Sesban exaltata* (Raf.) Rydb. occurs on the low grounds, stream banks, and fields of the coastal plains and adjacent provinces of Mississippi, Louisiana, Arkansas, Oklahoma, Texas, and Missouri.

There are no published data on the inoculation of sesban so far as the writers know; however, McKee puts it in the cowpea inoculation group. The writers have observed that sesban growing upon upland soils which were naturally inoculated for cowpeas failed to produce efficient nodules even though a few nodules occurred upon the roots. The work reported in this paper was therefore undertaken.

EXPERIMENTAL PROCEDURE

Inoculation tests with *Sesban exaltata* were conducted both in the greenhouse and in the field. The greenhouse tests were made in 4-inch sterile flower pots using sterilized sand and seed. Both negative and positive checks were used in each series of tests. The negative checks were made without inoculation, while the positive checks were made using sesban, cowpea, and garden bean seed inoculated with a culture suited to the particular plant. The results were not accepted unless the negative checks were free from nodules and the positive checks were well inoculated.

Nine strains of Rhizobia were isolated from sesban for these tests. Five strains were isolated from sesban growing wild on the banks of a stream near State College, three strains were obtained from sesban which had been planted on one area on the experiment station farm, and one strain was obtained from sesban which had been growing for several years on the experiment station farm at West Point, Mississippi. The sesban grown on the experiment station farms had not received artificial inoculation. In addition stock cultures of garden bean, cowpea, and other members of the cowpea cross-inoculation group—mungbean, hyacinth bean, peanut, lima bean, pigeon pea and lespedeza—were used.

The greenhouse tests were used for preliminary trials only, after which tests were conducted in the field to determine the efficiency of a more limited number of strains. The field tests were conducted on Oktibbeha fine sandy loam of pH 4.3. The sesban was planted in plats 1/400 acre in size. The plats consisted of a single row, 3½ feet wide and 31.1 feet long. Lime (dolomite) was applied in the drill at the rate of 400 pounds per acre; 250 pounds of 0-8-4 fertilizer were also applied in the drill with the seed.

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[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication November 26, 1937.

[2]Bacteriologist and Associate Agronomist, respectively.

[3]MCKEE, ROLAND. Summer crops for green manuring and soil improvement. U. S. D. A. Farmers' Bulletin 1750. 1935.

[4]SMALL, J. K. Manual of the Southern Flora. 1935. (Pages 702-703.)

The cowpea, peanut, and lima bean cultures used in the field experiments were combinations of two efficient strains of the particular group of Rhizobia. The pigeon pea, hyacinth bean, mungbean, peanut, lima bean, and sesban cultures were isolated by the senior author.

RESULTS AND DISCUSSION

The greenhouse data are qualitative only, while the field data are both qualitative and quantitative.

GREENHOUSE DATA

The data obtained in the greenhouse upon the ability of strains of cowpea, garden bean, and sesban Rhizobia to inoculate sesban are reported in Table 1.

TABLE 1.—*The ability of strains of cowpea, garden bean, and sesban Rhizobia to produce nodules on sesban in the greenhouse.*

Culture used	Source of culture	Nodules produced on		
		Cowpea	Sesban	Garden Bean
603, garden bean	U. S. Dept. Agr	None	Abundant	Abundant
605, garden bean	Univ. Wisc.	None	Good	Abundant
606, sesban	Miss. State	None	Abundant	Good
607, sesban	Miss. State	None	Abundant	Fair
608, sesban	Miss. State	None	Abundant	Abundant
609, sesban	Miss. State	None	Abundant	Fair
610–614, sesban	Miss. State	None	Abundant	Few
11, cowpea	Univ. Mo	Abundant	Few	None
15, cowpea	Stimugerm	Abundant	Few	None
20, cowpea	Univ. Ill	Abundant	None	Few
24, cowpea	Univ. Wisc	Abundant	Few	None
56, cowpea	Univ. Fla. beggerweed	Good	Few	Few
32, cowpea	Miss. State mungbean	Abundant	Few	Very few
34, cowpea	Miss. State hyacinth bean	Abundant	Few	None
38, cowpea	Miss. State peanut	Abundant	Good	Very few
42, cowpea	Miss. State lima bean	Abundant	Few	Abundant(?)
50, cowpea	Miss. State pigeon pea	Abundant	Few	Fair
55, cowpea	Univ. Fla. lespedeza	Abundant	Few	Few

The cowpea strains of Rhizobia produced nodules abundantly on cowpeas in all cases except one which is listed as good. They produced a few nodules on the sesban plant in 10 cases out of 11 and failed to produce any nodules in one case. The cowpea strains usually produce none to a few nodules on garden beans except in one case which was recorded as abundant. The latter data are probably in error.

The two garden bean strains of Rhizobia produced no nodules on cowpeas, good and abundant nodules on sesban, and abundant nodules on garden beans. Evidently the garden bean culture is able to produce nodules on sesban.

The Rhizobia isolated from sesban produced no nodules on cowpeas. As was noted above, sesban has been considered to be inocu-

lated by cowpea Rhizobia. The sesban cultures produced nodules abundantly on the sesban plants. In every case the garden bean inoculated with sesban culture produced nodules, varying from a few to abundant.

Summarizing the greenhouse work, it is seen that the cowpea cultures produce abundant nodules on cowpeas and usually a few nodules on sesban and garden beans. The garden bean cultures produce nodules on both sesban and garden beans but not on the cowpea, while the cultures isolated from sesban produce abundant nodules on sesban, a few on garden beans, and none on cowpeas.

FIELD DATA

The effect of strains of garden bean, cowpea, and sesban Rhizobia upon the yield and nitrogen content of sesban in the field is reported in Table 2.

TABLE 2.—*The effect of strains of cowpea, garden bean, and sesban Rhizobia upon the yield and nitrogen content of sesban.*

Culture	Source	Increase or decrease in yield per acre of air-dry sesban due to inoculation, as compared with check, pounds per acre	Percentage of nitrogen in air-dry sesban
603, garden bean.	U. S. Dept. Agr.....	−95±160*	1.01±0.086
605, garden bean.	Univ. Wis	−2±117	1.10±0.012
608, sesban . . .	Miss. State .	642±120	1.70±0.069
610, sesban. . .	Miss. State. .	822±143	1.80±0.076
613, sesban . .	Miss. State .	800±178	1.71±0.096
20–24, cowpea	Miss. State .	190± 97	1.11±0.094
38–39, cowpea	Miss. State peanut...	−90±126	0.99±0.049
42–43, cowpea .	Miss. State lima bean	22±157	1.07±0.049
Check		2,257	0.99±0.045

*Standard error.

The garden bean and the cowpea cultures did not increase the yield of sesban significantly in any case. The check yield was 2,257 pounds of air-dry sesban per acre. Cowpea culture produced 190 ± 97 pounds per acre more than the check. This increase is hardly significant. The three sesban cultures produced increases of 642 ± 120, 822 ± 143, and 800 ± 178 pounds standard error of air-dry sesban per acre. These increases are highly significant, but differences between them are not significant.

The sesban culture increased the percentage of nitrogen from 0.99 ± 0.045 to 1.70 ± 0.069, 1.80 ± 0.076, and 1.71 ± 0.906. These differences are highly significant, but, as in the case of yield, differences between them are not significant. The sesban inoculated with garden bean 605 had a nitrogen content of 1.10 ± 0.012 which, in comparison with the check, is barely significant. The other garden bean culture and the cowpea cultures did not increase the nitrogen content of sesban significantly.

SUMMARY

The ability of strains of garden bean, cowpea, and sesban Rhizobia to inoculate sesban was tested qualitatively in the greenhouse, using both negative and positive checks, and both qualitatively and quantitatively in the field with the following results:

1. Garden bean Rhizobia produced good to abundant nodulation on sesban.
2. Cowpea Rhizobia produced a few nodules on sesban.
3. Rhizobia isolated from sesban produced abundant and efficient nodulation on sesban.
4. The yields of sesban inoculated with sesban cultures were increased about 35%.
5. The percentages of nitrogen in sesban inoculated with sesban cultures were increased about 0.75%.
6. Strains of cowpea and garden bean Rhizobia did not increase the yield nor the nitrogen content of sesban significantly.

CONCLUSION

Inoculation of sesban with an efficient sesban culture will, in most cases, significantly improve sesban as a summer green manure. Sesban belongs to an inoculation group which is different from cowpea and garden bean. Until further work is carried out, sesban should be considered to be in the "Sesban Inoculation Group".

THE AMOUNT OF DUST IN THE AIR AT PLANT HEIGHT DURING WIND STORMS AT GOODWELL, OKLAHOMA, IN 1936–1937[1]

WRIGHT H. LANGHAM, RICHARD L. FOSTER, AND HARLEY A. DANIEL[2]

DUST storms are not new (6, 7),[3] but they have been more severe in the southern high plains and the adjacent territory since 1933 than in previous years. Few attempts have been made to measure their intensity and little information is available regarding the amount of soil which is present in the atmosphere. The continuation of dust storms of unusual severity during the past four years has developed a national interest in the problem of wind erosion and soil conservation. The agricultural significance of dust storms has been studied by various investigators and a review of recent literature was made by Daniel, Langham, and Foster (2). In this report some of the problems created by drifting soils, such as plant nutrient losses and changes in physical properties of soils, effect on machinery, railroads, highways, and on living conditions were described.

Several different methods have been used to collect dust from the air such as shallow pans containing water and tall containers with vertical walls which act as settling basins. In areas of high wind velocities only the heavier particles will collect in these types of containers. After the wind stops blowing, the dust in the air will settle, but it does not represent the movement of dust in any area. In order to estimate the amount of soil in the atmosphere under different conditions, the apparatus described below was introduced.

EXPERIMENTAL PROCEDURE

An impinger tube, as recommended by the Public Health Service (5) for measuring industrial dusts, was chosen as a means of removing the dust from the air. It was necessary to enlarge and modify the entire set-up since large quantities of dust traveling at a high velocity presented a decidedly different problem from factory and mine dusts which are collected from a quiet atmosphere.

The apparatus consists essentially of suction to draw the dust through the sampling device, a meter for measuring the air, and an impinger or sampling tube. An Electrolux vacuum cleaner was used as a source of suction and the air was measured with a 10-B metric gas meter. The impinger flask consisted of a 2½ by 18-inch hydrometer jar closed with a two-hole rubber stopper. One hole carried an outlet tube of 14-mm glass tubing bent to a right angle. The other hole carried the impinger tube. It was made by drawing a piece of 14-mm glass tubing down to a tip with a 5-mm orifice, and the tube was adjusted in the stopper so that the

[1]Contribution from the Oklahoma Agricultural Experiment Station, Stillwater, Okla. The work was conducted at the Panhandle Agricultural Experiment Station, Goodwell, Okla. Received for publication November 29, 1937.

[2]The authors wish to express their appreciation to Electrolux, Inc., and to the Panhandle Power and Light Company for use of vacuum cleaner and 10-B metric gas meter.

[3]Figures in parenthesis refer to "Literature Cited", p. 144.

narrow opening was about 1 cm from the bottom of the flask. The upper end of the tube was bent at a right angle making it parallel to the wind.

The three pieces of apparatus were arranged on a portable bench, as shown in Fig. 1, with the meter between the impinger flask and the vacuum cleaner. The suction end of the vacuum cleaner was connected to the outlet side of the meter and the inlet side was connected to the outlet of the impinger flask. All connections

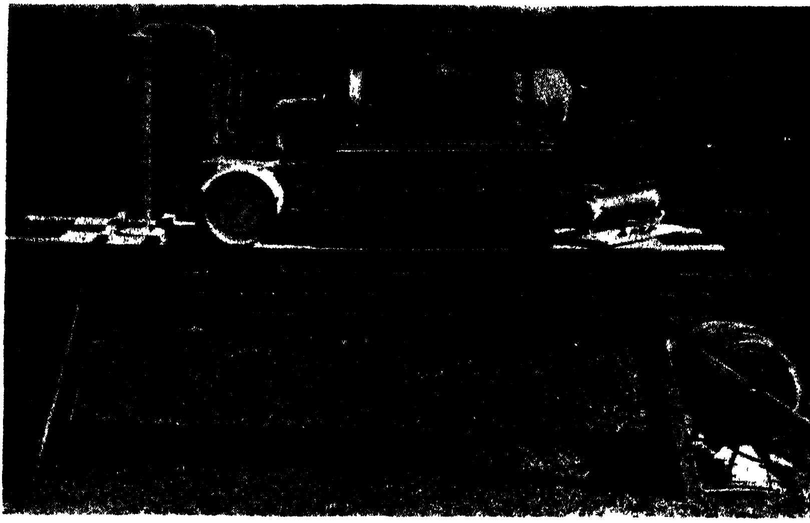

FIG. 1.—The machine used for collecting the dust.

were made with 14-mm glass tubing. The inlet and outlet to the meter were fitted with mercury manometers so that the decrease in pressure in the meter could be measured. The manometer readings were used to correct the meter reading to volume of air under atmospheric conditions.

The impinger flask was thoroughly cleaned and filled with distilled water to a depth of 4 or 5 inches. The apparatus was carried into the field of the Panhandle Experiment Station, 400 feet from buildings and other obstructing objects. Electricity was supplied by a long extension cord and the speed of the electric motor in the vacuum cleaner was reduced with a rheostat. The intake tube was placed at a height of 30 inches from the ground and turned directly into the wind. The time, meter reading, wind direction, wind velocity, manometer readings, and approximate visibility were taken during the test. The dust which was drawn in with the air was trapped in the water in the impinger flask. The flask was changed at convenient intervals, depending on the severity of the storm.

The quantity of dust was determined by evaporating the water and weighing the residue. The amount of dust in milligrams per cubic foot of air was determined by dividing the weight of dust in grams by the corrected volume of air passing through the impinger flask.

RESULTS

AMOUNT OF DUST IN AIR DURING WIND STORMS

The amount of dust carried by the wind in 29 dust storms in 1936 and 1937 was measured and the data recorded in Table 1. During this

TABLE 1.—*Dust content of air and visibility at Goodwell, Oklahoma, as affected by storms occurring from April 4, 1936, to May 3, 1937.*

Date of storm	No. of samples	Period of measurements per storms			Wind velocities, miles per hour	General wind direction	Approximate visibility, yards	Milligrams of dust per cubic foot of air*
		Clock start	Hours end	Total minutes sampled				
				1936				
Apr. 4	3	2:24 p.m.	3:52 p.m.	46	23.0±4.0	W–SW	70±24	57±10
5	2	11:44 a.m.	3:22 p.m.	60	26.0±0.0	N–NE	80±0	40±5
8	2	11:16 a.m.	3:22 p.m.	90	24.5±1.5	S–SW	667±178	7±3
9	2	9:47 a.m.	11:08 a.m.	45	32.0±0.0	N–NE	112±81	62±17
20	3	6:23 p.m.	7:19 p.m.	37	30.0±0.0	N	28±18	102±48
23	5	9:12 a.m.	2:52 p.m.	311	24.4±17.2	S–SW	630±274	9±4
29	2	5:22 p.m.	6:45 p.m.	78	20.5±4.5	SW	550±160	6±2
May 5	6	3:00 p.m.	7:41 p.m.	143	23.3±2.0	S–SW–SE	238±169	32±13
8	2	3:55 p.m.	5:15 p.m.	70	22.5±2.5	NW	38±24	67±22
				1937				
Feb. 7	1	11:00 a.m.	7:20 p.m.	500	30.0±0.0	SW	105±95	55±0
11	1	2:40 p.m.	6:25 p.m.	225	23.0±0.0	S–SW	400±00	6±0
14	3	8:30 a.m.	3:03 p.m.	405	24.3±3.4	S–SW*	150±14	38±24
15	2	10:40 a.m.	5:30 p.m.	380	19.0±1.0	NW–N	285±80	5±2
16	6	10:00 a.m.	5:40 p.m.	432	25.5±2.2	S–SW	333±386	48±40
17	3	8:50 a.m.	3:05 p.m.	370	21.5±2.5	N–NE	126±158	8±6
18	2	12:55 p.m.	5:40 p.m.	133	32.0±0.0	SW	146±147	50±44
Mar. 3	5	9:55 a.m.	7:21 p.m.	617	20.7±7.8	NW–N	181±56	8±2
9	3	9:25 a.m.	1:20 p.m.	235	22.5±2.7	SW–W	472±343	19±12
17†	1	12:55 p.m.	2:40 p.m.	105	17.1±0.0	N–NE	440±00	5±0
19	6	12:30 p.m.	6:37 p.m.	363	21.4±1.2	NW–N	88±62	39±14
23	7	9:30 a.m.	10:30 p.m.	822	30.0±1.0	SW	21±23	115±32
24	5	10:04 a.m.	8:20 p.m.	676	19.8±2.8	NW–N	90±100	43±25
Apr. 2	3	9:19 a.m.	5:55 p.m.	501	18.4±3.9	SW	540±272	10±5
3	3	8:53 a.m.	2:05 p.m.	300	14.0±1.3	N	465±107	6±4
6	4	1:34 p.m.	6:43 p.m.	300	24.4±1.5	SW	155±109	29±18
16	4	9:48 a.m.	5:58 p.m.	480	20.7±1.3	SW	251±108	12±7
22	4	1:32 p.m.	6:52 p.m.	300	21.1±2.8	SW	147±92	30±14
23	4	8:30 a.m.	4:47 p.m.	335	19.2±4.2	NW–N	319±273	33±20
May 3	5	8:40 a.m.	7:38 p.m.	656	23.4±1.3	NW	426±226	13±7
Average	3.4			311	23.2±2.5		260±123	33±14

*Measurements were all taken about 30 inches above the surface of the ground.

period 27 determinations were made in 9 major storms occurring from April 4 to May 8, 1936, and 74 in 20 severe storms from February 7 to May 3, 1937. Many dust storms began and ended during the night, and since the apparatus could not be kept in continuous operation or set up in time to measure the beginning of each blow, the amount of dust per cubic foot of air for a complete storm was not always obtained. When such conditions occurred, attempts were made to take at least one sample at a time when the storm appeared to reach a maximum intensity. Due to numerous complications, only two dust storms in 1936 (April 23 and May 5) were measured throughout their duration. Complete results were recorded from several storms in 1937.

The average of all readings taken in a particular storm was calculated and considered representative of the amount of dust in the air during a period of high wind. Owing to variable nature of the wind, considerable variation occurred in the results obtained during a continuous dusty period and also between different storms The average amount of dust collected from the air during all storms was 33 ± 14 milligrams per cubic foot. In these experiments the dust was collected about 30 inches above the ground and the data do not show the quantity of soil drifting away from the high plains. According to Udden, cited by Twenhofel (7), "on the average, 850,000,000 tons of dust are carried in the Mississippi Valley 1,440 miles each year". He also states that the dust carried in the atmosphere over the Mississippi Valley is one thousand times as great as the quantity of sediment transported by the Mississippi River system.

Since measurements were not taken throughout the dusty season in 1936, a more reliable comparison of severity of storms may be obtained from the data in Table 2. The years of 1933, 1934, and 1935 contained 70, 22, and 53 days, respectively, that had sufficient dust to lower visibility in comparison with 73 for 1936, and 117 from January 1 to August 1, 1937. Although visibility data in Table 1 were determined from observations, they do give a general idea of vision

TABLE 2.—*The number of days containing sufficient dust to lower visibility at Goodwell, Oklahoma, from January 1, 1933, to August 1, 1937.*

Month	Year					Average
	1933	1934	1935	1936	1937	
Jan.	4	2	2	0	9	3.4
Feb.	4	0	7	9	14	6.8
Mar.	14	6	11	18	18	13.4
Apr.	17	6	20	16	21	16.0
May	12	2	6	14	23	11.4
June	7	2	1	1	17	5.6
July	3	0	1	2	15	4.2
Aug.	3	1	1	1	—	1.5
Sept.	3	0	0	0	—	0.8
Oct.	0	1	2	1	—	1.0
Nov.	2	2	1	7	—	2.4
Dec.	1	0	1	4	—	1.5
Total	70	22	53	73	117	68.0

during some of the storms at Goodwell, Oklahoma. Visibility was reduced to one-half mile or less in 72 storms that occurred in 1937. In 23 of these particular storms vision was 150 feet or less. Average wind velocity is highest during March, April, and May (4), and the greatest number of dusty days occurred during these months. With the exception of this year, there have been only three months of severe dust each season. In 1937 the soil continued to blow from January 1 to August 1 which was the last date of the observations included in this report.

Although dust storms may occur from almost any direction, the prevailing wind is from the southwest (4) in the Panhandle of Oklahoma. The average wind velocity (3) from 1925 to 1934, inclusive, was 7.9 miles per hour, while that reported during these storms averaged 23.2 ± 2.5 miles per hour. The amount of dust in the air appears to be proportional to the wind velocity during a single storm; but, in different windy periods, there was probably no relation. This information substantiates conclusions drawn from general observations that wind turbulence is also an important factor in soil movement in this locality.

Storms in the past have varied in length from a few minutes to several hours and occasionally four or five have occurred in succession. They usually stop for a few hours in the afternoon or night and begin again from the opposite direction. Observations indicate that the duration of the average dust storm was about 10 hours dur-

FIG. 2.—The great black rolling dust storm that passed over Goodwell, Okla., May 21, 1937.

ing the dusty season. These storms have been of two types, the typical hard blows, and the great black blizzards (1) which apparently resulted from a well-developed polar front. The former type usually starts in the morning from the south or southwest continuing as the wind changes to the northwest or north until late afternoon or into the night. The black rolling type, Fig. 2, sweeps the plains at high velocities and produce an interval of total darkness followed by almost zero visibility for a considerable period. Only four of these storms have occurred in recent years. The first of known record was in June, 1922, the next was on April 14, 1935. Two of these storms occurred in 1937, the first on May 21 and the second on June 4.

SUMMARY

Measurements were made with an impinger tube to determine the amount of dust per cubic foot of air at various times during 29 dust storms of 1936 and 1937 occurring at Goodwell, Oklahoma. The average amount of dust collected in all storms was 33 ± 14 milligrams per cubic foot of air. The average wind velocity during these storms was 23.2 ± 2.5 miles per hour.

A record of the number of dusty days occurring at Goodwell, Oklahoma, from January 1, 1933, to August 1, 1937, shows that there were 70 dusty days in 1933, 22 in 1934, 53 in 1935, 73 in 1936, and 117 from January 1 to August 1, 1937.

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COOPERATIVE PRODUCTION OF FOUNDATION STOCKS FOR CERTIFIED CORN HYBRIDS IN OHIO[1]

R. D. Lewis and G. H. Stringfield[2]

A PLANNED program for the production of seed of adapted corn hybrids has been developed in Ohio to the point where in 1937, 260 growers produced commercial supplies of seed and a group of 320 apprentices were gaining experience with 1/8 or 1/4 acre crossing plats. By 1937 seed production had been initiated in each of the 88 counties. This cooperative research-extension production program is designed to make available reliable seed of adapted hybrids at a price consistent with the best interests of producers and users.

In developing a trained personnel for the production of hybrids, the Ohio program has given similar opportunities to small and large producers, these opportunities being based on interest, abilities, and nature of services rendered. Most of the producers in Ohio have crossing plats of relatively small acreages. In 1937, 68% of the commercial growers of certified hybrids in Ohio had crossing plats of 10 or fewer acres, 23% had crossing plats ranging from 11 to 50 acres, 5% had crossing plats of 51 to 100 acres, and only 4% of the producers had over 100 acres in crossing plats.

Inbred lines developed in Ohio were released to qualified growers for the first time in 1937. From 1933 to 1937, the Experiment Station, in cooperation with the Extension Service, the Bureau of Plant Industry, and two trained growers, accepted the responsibility for the production and distribution of foundation seed stocks of single crosses. This was a proper function and responsibility of the Experiment Station during the initial period of rapid development and change, for it assured effective use of materials created by research, gave time for the development of trained personnel, assured seed stocks to small as well as large producers, and made possible the correlation of production, distribution, and use of foundation seed stocks.

But in 1936 it became evident that the Experiment Station could not provide sufficient personnel nor physical equipment to produce and distribute the great volume of seed stocks that would be required in 1938. Also, the required activities of the research and extension staffs in seed stock activities were diverting time, energies, and thoughts from the fundamental research and educational programs. To build up reserve supplies of seed stocks, financing would be required. Research and extension leaders in the program, together with

[1]Contribution from the Ohio State University, the Ohio Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1, 1937. Received for publication December 9, 1937.

[2]Professor of Agronomy Extension, Ohio State University, and Agent, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; and Agronomist in Corn Investigations, Ohio Agricultural Experiment Station, and Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

a considerable group of producers who were giving thought to the future, concluded early in 1937 that the time had come for seed producers to take a more active part in making the results of research and extension efforts available to themselves, that they must begin to bear more of the costs and do more of the planning in order to be in a position to continue as producers and to assure themselves of having seed stocks available for producing the best new hybrids developed by public research institutions.

A committee of seven was elected by the growers at the Corn Hybrid School in January of 1937 to deliberate on problems and suggest actions that might aid the Ohio program for production and use of adapted hybrids. Recognizing at once the need for a cooperative program of attack on seed stocks problems, this committee, working with an advisory group from the Experiment Station and Extension Service, rapidly developed an outline of the form, functions, and activities of a cooperative seed stocks organization.

On February 18, 1937, the trustees formed a corporation, not for profit, and designated it the "Ohio Hybrid Seed Corn Producers". The main features of the set-up of the organization and its activities and relationships are detailed in Fig. 1.

Membership in the organization is open to persons, partnerships, or corporations who have been accepted as apprentice growers in the cooperative research-extension hybrid corn project of the Experiment Station, the Extension Service, and U. S. Bureau of Plant Industry, and those who have produced or are producing seed of corn hybrids under inspection and certification through the Ohio Seed Improvement Association. The membership entrance fee is $5.00. The organization is governed by a Board of Trustees of seven members, each serving three years, two or three elected annually. An executive committee of three trustees conducts most of the current business. The Advisory Board is created by the Board of Trustees and must include two representatives from the Agronomy Department of the Experiment Station, one from the Extension Service, and the President of the Ohio Seed Improvement Association.

Late in February 1937 a statement, prepared and signed by the principals in the research-extension program of the Experiment Station, the Extension Service, and the Bureau of Plant Industry, was sent to all growers participating in the cooperative hybrid corn projects. This statement analyzed present and future problems and possible solutions in the production and distribution of foundation seed stocks in Ohio. Significant approval of the formation of the Ohio Hybrid Seed Corn Producers was combined with the announcements (1) that existing contracts and reserve seed stocks of the Experiment Station for production of released inbred lines and single crosses were offered for the use of the organization; (2) that the Experiment Station would no longer supply commercial producers of seed of corn hybrids with single crosses involving released inbred lines; and finally (3) that members of the research-extension staff would act as advisors in developing cooperative forward-looking seed stock programs.

The trustees followed the above statement with a formal announcement of the organization and a tentative outline of plans for 1937.

Membership applications and fees were solicited. To finance activities during 1937, an advance or reservation payment of \$2.00 per acre on the number of acres of double crossing plats estimated for production in 1938 was asked from each member.

The response from prospective members was so prompt and enthusiastic that in early March the trustees appointed a competent full-time manager, and authorized the 1937 production program for seed stocks as developed by the manager and the advisory board.

On November 10, 1937, the membership had reached 377, and these members had reserved, by a \$2.00 per acre advance payment, foundation single crosses for planting 7,100 acres of double crossing plats in 1938. It is estimated that the organization has from its 1937 operations sufficient seed of required single crosses for planting at least 13,000 acres of double crossing plats.

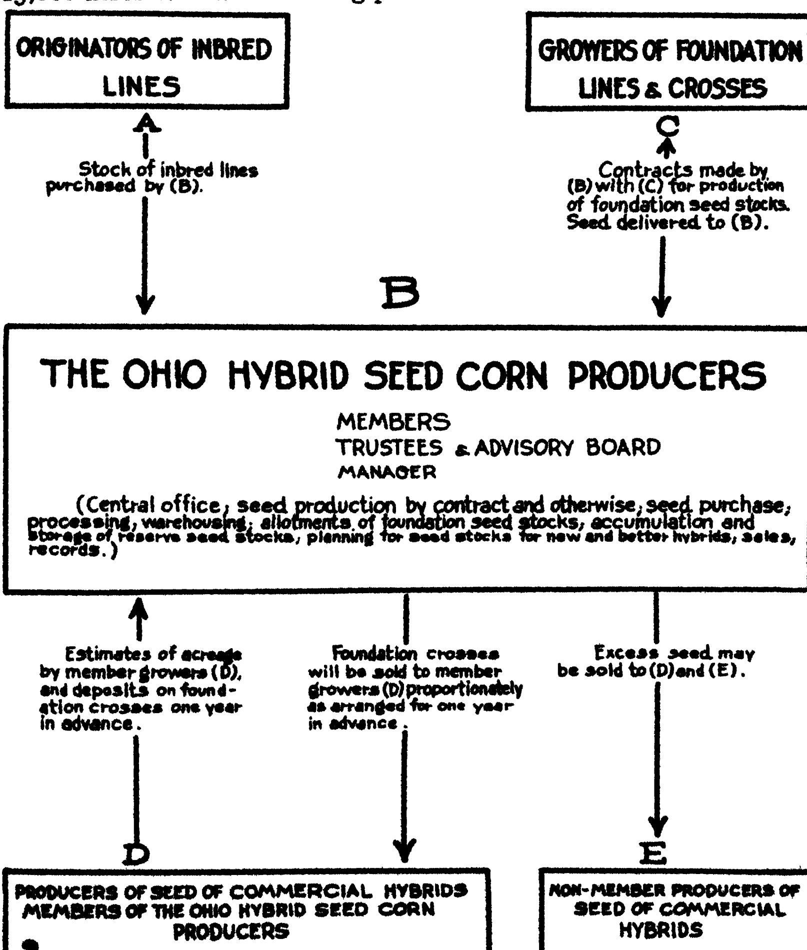

FIG. 1.—Diagram showing the seed stock activities of the Ohio Hybrid Seed Corn Producers, incorporated February 18, 1937.

Foundation seed stocks of single crosses and inbred lines were produced under contracts with 42 members in 25 different counties, with a total of 65 different plats and 198 acres. To distribute production risks each single cross was produced in from two to five crossing plats. Even in 1937 this proved desirable. The seed used in planting each of these plats came directly from releases by the Experiment Station or from certified seed stocks produced in 1936. Also, the Experiment Station produced for the organization seed stocks of a few lines and single crosses that are to be released in 1938. The organization also contracted with other seed stock producing agencies for 35 million viable seeds of single crosses to be used in producing certain hybrids developed out of the state and now eligible for certification in Ohio. Adequate reserve supplies of hand-pollinated seed of 20 inbred lines were also produced direct from originator's foundation seed stocks for the Ohio Hybrid Seed Corn Producers.

Foundation seed stocks of the following five classes were thus produced for and by the members of the cooperative seed stocks organization in 1937: (1) Inbred lines, hand-pollinated; (2) inbred lines, isolated plat increases; (3) inbred lines, from male rows of single crossing plats, eligible only for use as "female" hereafter; (4) First generation single crosses; and (5) advanced generation of single crosses, advanced in isolated plats from F_1 seed, the only type of advance generation seed eligible for use in producing certified hybrids in Ohio in 1938.

All plats were inspected for certification through the Ohio Seed Improvement Association and all the seed is being inspected during processing and preparation for distribution. A contract with a grower of foundation seed provides that for seed rejected through his failure to meet the requirements for certification, only a nominal acre rate is paid him, but if the seed meets all conditions of the contract and certification requirements, the grower receives a sufficient sum per acre to encourage the greatest of care in producing and handling the seed. Bonuses are provided for higher than average production of foundation seed stocks.

The Ohio Hybrid Seed Corn Producers maintain at Croton, Licking County, Ohio, a two-story, hollow tile, seed warehouse. A bin-type dryer and excellent special equipment are owned by the organization for drying, shelling, grading, storing, and distributing the seed stocks. To date the organization has had to borrow no money and even has a balance to finance operations until such seed stocks distribution and sales collections are initiated in January 1938. Final payments on contracts for seed produced in 1937 are due on April 1, though the contract growers are allowed a 6% per annum carrying charge from October 1 to April 1.

Most of the members have indicated those hybrids for which they wish to have the parent single crosses. However, as certain new hybrids are coming into prominence, shifts may be made by those desiring to do so, insofar as seed stocks permit. Seed stocks are to be distributed at a determined price per 1,000 viable kernels. The number of viable seeds per pound is calculated and appears on the tag attached to each lot of foundation seed. Such a method is far superior to price per pound for it automatically makes adjustments for variations in

sizes of seed and viability of different inbred lines and single crosses. The producer can at once calculate the number of pounds to plant per acre to secure the desired stands in his crossing plats.

Because of the favorable experiences of 1937, certain simplifications can be made in the program of the organization for 1938. Fewer plats will be required, especially for isolated inbred lines. For each inbred line two or three such plats were produced in 1937, and most of them came through successfully so that an abundance of seed is available for 1938 and future years. Because of probable reserve supplies of certain single crosses, the number of such plats may be reduced. There will also be a tendency to increase the size, but reduce the number, of crossing plats for other single crosses.

It will also be the policy of the organization to go even farther than certification regulations specify in use of hand-pollinated seed of inbred lines and in isolation requirements. Close observance of these procedures will facilitate the work of the organization and eliminate many of the possible sources of contamination of seed stocks.

For the following reasons, a cooperative seed stocks organization of the type of the Ohio Hybrid Seed Corn Producers functions as an essential and effective aid to the progress of a hybrid corn program such as obtains in Ohio:

1. The production of the numerous kinds of seed stocks is concentrated under the direction of trained personnel and in large enough quantities to cut down overhead costs.
2. Producers, small and large, are assured access to adequate supplies of pure seed of foundation stocks for producing up-to-date, not obsolete, hybrids.
3. The seed stocks can be rigidly controlled. Poor and obsolete ones can be discarded easily since any loss is distributed among the cooperating group.
4. The numerous risks, due to poor pollination, insufficient isolation, drouths, floods, insects, livestock, unavoidable contaminations, etc., are distributed.
5. The accumulation of reserve supplies is facilitated and financed against situations in later years when seed stocks of one or more types might be distressingly short.
6. The group or sub-groups of seed producers can effectively anticipate and plan for the early initiation of production of superior new hybrids.

PREFERENCES FOR CERTAIN GENETIC STRAINS OF CORN EXHIBITED BY ANIMALS[1]

E. Roberts, J. R. Holbert, and J. H. Quisenberry[2]

DURING storage certain strains of corn differing genetically were consistently badly damaged by mice and rats, while other strains were damaged only slightly or not at all, though all were equally accessible. Fig. 1 shows two hybrids Ax90 and Ax98, the latter badly damaged. The soiled spots on ears in sample Ax90 were caused by mice, but they preferred Ax98.

The results of a study of six strains of the 1932 crop, recording the number of ears, percentage of ears sampled, and the extent to which the ears were damaged by mice, are given in Table 1. Inbred Hy would probably have been damaged to a much greater extent had not special precautions been taken to protect this strain from the mice. Among the strains, 176A open-pollinated and Inbred Hy of Group I and Hy of Group II are distinctly preferred by mice, while Inbred Leaming suffered no damage.

Table 1.—*Damage by mice to various strains of corn of the crop of 1932 in the storage house.*

Strain*	No. of ears tested	Ears damaged %	Percentage of ears damaged to extent of			
			1–5 kernels	6–15 kernels	16–50 kernels	50+ kernels
		Group I†				
176A	195	19.0	13.3	3.1	1.6	1.0
B-120	125	10.4	6.4	2.4	0.8	0.8
Leaming	97	0.0	0.0	0.0	0.0	0.0
Hy	93	25.7	4.3	3.2	6.4	11.8
		Group II†				
RyD_3	500	9.0	7.0	1.6	0.0	0.4
Hy	446	36.8	16.2	15.9	2.9	1.8

*The grain used in this trial consisted of open-pollinated seed of 176A and sib-pollinated seed of all other strains.
†A group consists of lines produced under comparable soil and climatic conditions.

Another study was made of the damage occurring among other strains of the 1935 crop. (See Table 2.) AxHy of Group I, R_4xHy of Group II, and AxHy of Group III were damaged to a much greater extent than were the other strains, both on the basis of number of ears and the mean number of kernels per ear. With the exception of 90xHy the crosses involving Hy were preferred. The hybrid 90xHy was distinctly lower in preference. A summary of these observations

[1]Cooperative investigation between the Illinois Agricultural Experiment Station, Urbana, Ill., and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication December 9, 1937.

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has already been published (6).[3] The preference for Ax90 as noted above was distinctly less than that for Ax98. Mr. C. W. Holmes of Edelstein, Illinois, reported in correspondence the feeding of equal

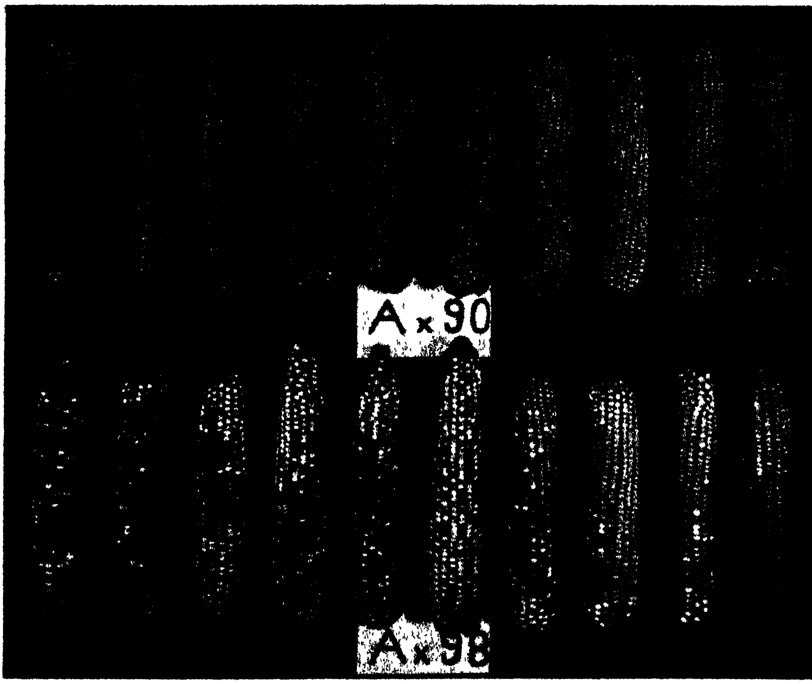

FIG. 1.—Both kinds of corn were equally accessible to mice, but the hybrid Ax98 was much more badly damaged than Ax90, indicating a preference for the former.

TABLE 2.—*Damage by mice to various strains of corn of the 1935 crop in the storage house.*

Strain	No. of ears observed	Ears damaged %	Mean No. of kernels damaged per ear	Difference	Standard error of difference	D/SE
			Group I*			
A×Hy......	54	98.2	21.6	17.7	8.1	2.19
A×L.......	61	45.9	3.9	—	—	—
			Group II*			
R₄×Hy.....	70	98.6	44.2	41.7	7.4	5.64
R₄×L31782	66	43.9	2.5	—	—	—
			Group III*			
A×Hy.....	65	86.2	39.6	38.4	7.5	5.12
90×Hy.....	58	34.5	1.2	—	—	—

*A group consists of lines produced under comparable soil and climatic conditions.

[3]Figures in parenthesis refer to "Literature Cited", p. 159.

quantities of 317x540 and 317x90 to swine and that they consumed all of 317x540 before eating any of 317x90. Mr. Holmes knew nothing of our work on preferences.

In a laboratory test with mice in 1933, using corn produced in 1932, three ears of each of nine strains [inbred lines A, B, Hy, IB, L, R_4, RyD_3, and three-way crosses $(AxC_2)xL$, and $(HyxR_4)xL$] were placed in a circular cage as shown in Fig. 2, so that any two ears of the same strain were separated by eight ears of the other strains. Circular cages were used in this and other tests in order that position in the cage would not be an interfering factor. Table 3 summarizes weights of grain eaten and kernels damaged. Strain IB is the one distinctly preferred by the animals. A test was made with 12 mice, using inbred lines A, B, Hy, L, R_4, and RyD_3, with only one ear of each strain. The test lasted 5 days. Table 4 gives the results. For strain B a strong preference was indicated. In the experiment where B and IB both were included (Table 3), B was less preferred by the animals than was IB.

TABLE 3.—*Summary of damage to whole ears of corn (1933) two tests with six mice each, 6-day periods.*

Strain	Weight of grain eaten, grams			Total No. kernels	Damaged kernels	
	Test 1	Test 2	Total		No.	%
A†	5.5	6.9	12.4	2,792	178	6.4
B†	10.8	18.5	29.3	4,875	607	12.5
Hy†	9.9	32.2	42.1	2,147	790	36.8
IB†	28.0	168.1	196.1	3,907	1,813	46.4
L†	3.2	9.1	12.3	2,014	61	3.0
R_4†	5.1	7.0	12.1	2,594	179	6.9
RyD_3†	5.9	9.7	15.6	3,296	213	6.5
$F_1(A\times C_2)\times L$	14.6	8.5*	23.1*	3,942	626*	15.9
$F_1(Hy\times R_4)\times L$	37.4	39.8*	77.2*	3,434	876*	25.5

*Only one ear of this variety in test 2.
†Sib-pollinated seed used.

TABLE 4.—*Summary of damage in two tests in which 12 mice were fed for 5-day periods.*

Strain*	No. of observed kernels	Kernels damaged		Weight of grain eaten, grams
		No.	%	
A	405	55	13.6	4.5
B	712	383	53.8	138.5
Hy	409	11	2.7	14.5
L	352	2	0.6	2.5
R_4	310	24	7.7	6.5
RyD_3	479	5	1.0	2.5

*Sib-pollinated seed used in each case.

In 1934 three tests of two cages each with two ears of each of four inbred lines (Hy, K, R_4, and 90) in each cage were made with mice, each cage containing six mice with the exception of one which had

five. As in other tests the samples of corn belonging to the same strain were separated by placing samples of the other strains between the two of the same strain. Table 5 gives the results. Kernels were pulled from the ears with little damage to the kernels. Hy had only 3.1% of the kernels missing while 90 had 56.0%, but of the kernels remaining on the ears 32.5% of Hy were damaged and of 90 only 0.26%. Distinct preference was again exhibited in these tests.

FIG. 2.—Method of arranging ears of corn in circular cage.

TABLE 5.—*Tests of four strains of corn with mice (1934).*

Strain*	No. of ears observed	No. of kernels observed	Kernels missing		Damaged kernels among those remaining	
			No.	%	No.	%
			Test I			
Hy....	4	1,807	7	0.39	814	45.22
K.....	4	1,138	231	20.30	3	0.33
R_4.....	4	2,027	252	12.43	281	15.84
90....	4	2,209	1,170	52.97	3	0.29
			Test II			
Hy.....	2	1,000	2	0.2	686	68.74
K......	2	491	95	19.35	2	0.51
R_4......	2	823	303	36.82	44	8.46
90......	2	1,024	790	77.15	3	1.28
			Test III			
Hy.....	4	1,895	75	3.96	3	0.16
K......	4	1,029	485	47.13	2	0.37
R_4......	4	1,798	1,123	62.46	23	3.41
90......	4	1,938	936	48.30	0	0.0
			Total			
Hy.....	10	4,702	84	3.11	1,503	32.55
K......	10	2,658	811	30.51	7	0.38
R_4......	10	4,648	1,678	36.10	348	11.72
90......	10	5,171	2,896	56.00	6	0.26

*Sib-pollinated seed used in each case.

Ear corn was also used with rats, but the test was not very satisfactory because the rats pulled the grains from the cob, eating largely the germs. The following records were made:

A—damage slight, 1.5 grams of kernels destroyed
B—damage slight, 4.5 grams of kernels destroyed
Hy—damage slight, 1.0 grams of kernels destroyed
L—damage severe, 43.0 grams of kernels destroyed
R_4—damage slight, 3.0 grams of kernels destroyed
RyD_3—damage complete, 144.0 grams of kernels destroyed

Several tests were made with rats, using ground corn. This made possible more accurate measurements of the amounts eaten. The feed dishes were placed in circular cages as shown in Fig. 3. The order of the dishes was changed when a trial was repeated. One trial consisted of two cages with nine strains of corn [inbred lines A, B, Hy, IB, L, R_4, and RyD_3 and three-way crosses $(AxC_2)xL$, and $(HyxR_4)xL$], with one rat in each cage. Each rat was used for two 6-day periods. The results are given in Table 6. Strains $(AxC_2)xL$ and $(HyxR_4)xL$ were consistently eaten in preference to the other strains. In another test involving two rats with these two strains and IB left out, the average amounts of meal (in grams) eaten were as follows: A, 6.3; B, 39.8; Hy, 0.8; L, 4.7; R_4, 9.0; RyD_3, 18.3. In this test the greatest preference is shown for B, as was also shown by mice in Table 4.

Table 7 gives the amounts of corn eaten when seven inbred lines (A, B, Hy, K, L, RyD_3, and 90) were in the test at the same time.

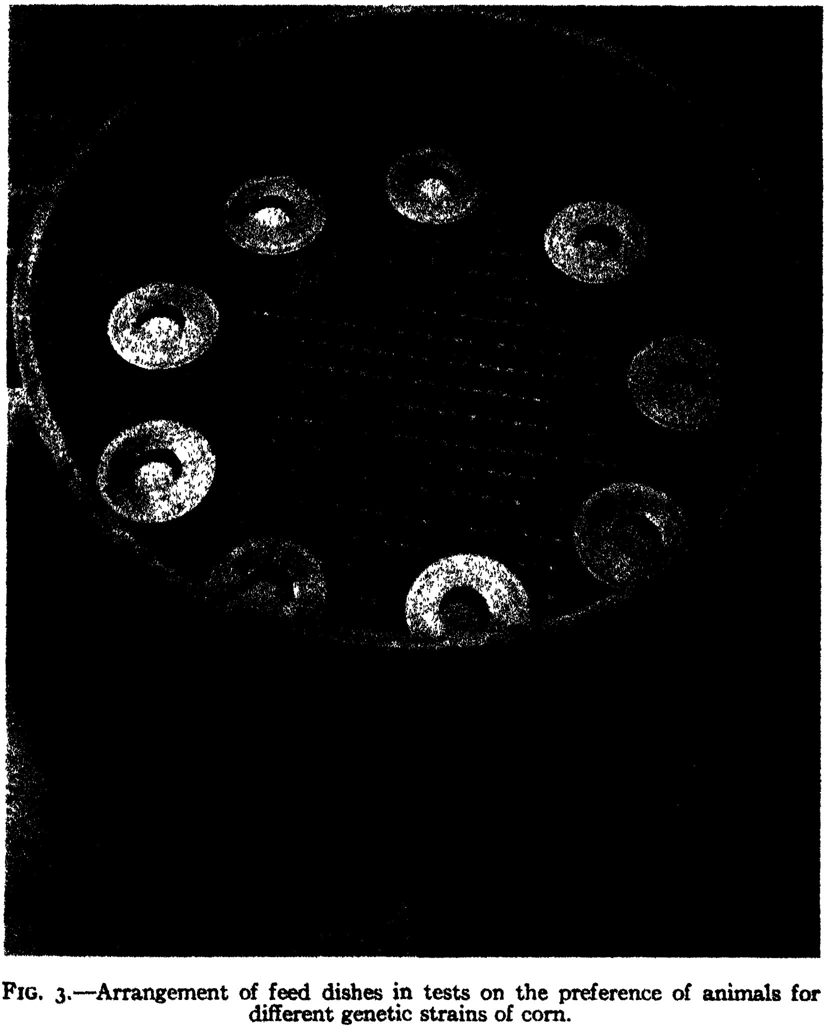

FIG. 3.—Arrangement of feed dishes in tests on the preference of animals for different genetic strains of corn.

RyD_3 was distinctly preferred with B in second place. Fig. 4 shows the total amounts eaten. A summary of these trials was published by Roberts and Quisenberry (5). The records were also studied on the basis of the average amount in grams eaten daily per 100 grams of weight of rat. These averages with probable errors are given in Table 8.

These seven inbred lines were also tested three at a time, the results of these tests being given in Table 9. With A, B, and Hy in combination, A was preferred; with K, L, and RyD_3, RyD_3 was prefered; and with A, RyD_3, and 90, RyD_3 was also preferred.

TABLE 6.—*Amounts of ground corn eaten by rats 3 and 4 on two successive trials (1933).*

Strain	Grams of corn eaten by Rat No. 3			Grams of corn eaten by Rat No. 4			Average amount for both rats, grams
	Trial 1	Trial 2	Ave.	Trial 1	Trial 2	Ave.	
A*.	1.5	2.0	1.75	1.5	0.0	0.75	1.25
B*	3.0	5.0	4.00	2.5	0.5	1.50	2.75
Hy*	0.5	0.5	0.50	1.5	1.0	1.25	0.88
IB*	6.5	11.5	9.00	6.0	13.0	9.50	9.25
L*	0.5	5.5	3.00	7.5	6.0	6.75	4.88
R_4*	0.5	0.5	0.50	1.5	0.0	0.75	0.63
RyD_3*	6.5	1.5	4.00	4.5	3.5	4.00	4.00
$F_1(A \times C_2) \times L$	68.5	24.0	46.25	77.0	22.0	49.50	47.88
$F_1(Hy \times R_4) \times L$	12.5	22.7	17.60	39.5	51.0	45.25	31.43

*Sib-pollinated seed used.

TABLE 7.—*Summary of amounts of seven strains of ground corn eaten by rats (1934).*

Strain*	No. of tests	No. of rats	Total days	Total eaten in grams	Eaten daily per rat in grams
A	13	36	37	231	1.04
B	13	36	37	478	2.15
Hy	13	36	37	237	1.07
K	13	36	37	429	1.93
L	13	36	37	350	1.58
RyD_3	13	36	37	1,307	5.89
90	13	36	37	181	0.82

*Sib-pollinated seed used in each case.

TABLE 8.—*Means and probable errors of amounts of ground corn eaten by rats per 100 grams live weight computed from the data in Table 7.*

Strain*	Average eaten daily in grams per 100 grams rat	Probable error
RyD_3	3.69	0.224
B	1.38	0.214
K	0.98	0.200
L	0.78	0.171
Hy	0.70	0.167
A	0.55	0.119
90	0.52	0.062

*Sib-pollinated seed used in each case.

The significance of the differences between amounts of RyD_3 and B eaten is P = .9934 or 1:151 in favor of RyD_3. Between RyD_3 and 90 P = .9991 or 1:1110 in favor of RyD_3.

When RyD_3, K, and L were together in the test, for the difference in amounts eaten per day between RyD_3 and L, P = .999 or 1:999 in favor of RyD_3.

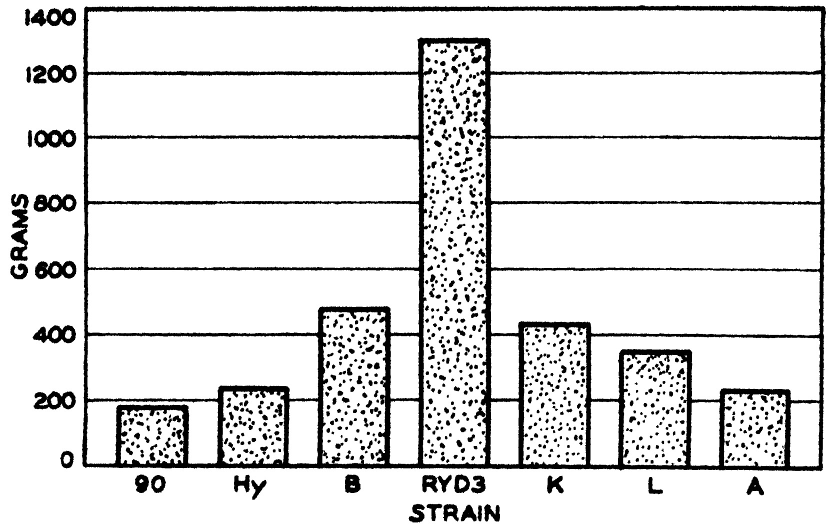

FIG. 4.—Variations in amounts of different strains of ground corn eaten by rats. The animals showed a distinct preference for strain RYD_3, of which 1,307 grams were consumed. Next in popularity was strain B, with 477.5 grams consumed. Strain 90, with only 181 grams eaten, was the least popular.

TABLE 9.—*Summary of amounts of ground corn eaten by rats with three strains of corn present at a time (1934).*

Strain*	No. of tests	No. of rats	Total days	Total eaten in grams	Eaten daily per rat in grams
A..	2	6	7	152	3.61
B......................	2	6	7	116	2.75
Hy....................	2	6	7	65	1.55
K......................	2	6	7	50	1.19
L......................	2	6	7	74	1.75
RyD_3................	2	6	7	203	4.83
A......................	2	6	6	75	2.08
RyD_3................	2	6	6	197	5.46
90....................	2	6	6	55	1.51

*Sib-pollinated seed used in each case.

With A, RyD_3, and 90 together, considering the amounts of RyD_3 and 90 eaten, the significance of the difference is P = .9966, or 1:293 in favor of RyD_3.

The 1935 tests with rats, using ground corn, are summarized in Table 10. In all tests the crossed strains in which inbred 90 appears, with the exception of one, less was eaten. Inbred 90 was also less preferred than 98 and RyD_3. Inbred A was also less preferred than were some of the other strains. A summary of these tests has already been published (6).

TABLE 10.—*Summary of amounts in grams of ground corn eaten by rats with strains A, 90, 98, RyD_3, A×98, RyD_3×A, RyD_3×90, and A×90 in various combinations (1935).*

Strain	No. of rats	No. of tests	Total days	Total eaten in grams	Average eaten per day, grams
A*	6	2	6	91	2.53
90*	6	2	6	65	1.81
98*	6	2	6	137	3.81
A×90	6	2	6	95	2.64
A×98	6	2	6	86	2.39
A*	6	2	6	45	1.28
RyD_3*	6	2	6	392	10.89
90*	6	2	6	53	1.47
98*	6	2	6	196	5.44
A×90	6	2	6	122	3.39
A×98	6	2	6	199	5.53
RyD_3×A	6	2	6	190	5.28
RyD_3×90	6	2	6	62	1.72
A×90	6	2	6	224	6.22
A×98	6	2	6	304	8.44

*Sib-pollinated seed used.

Reasons for the preferences exhibited in these tests have not been studied. Studies of this phase of the problem are very important and should include the morphological structure of the kernel, especially differences in hardness; and chemical composition with particular reference to differences in odor and vitamin content. Also possible differences in animals should be considered. In some of our tests a few animals were found which seemed to exhibit no preference, eating from all the strains indiscriminately, while others had distinct preferences.

Hereditary differences in man in respect to the taste of phenyl-thio-carbamide have been reported by Blakeslee and Fox (1). To some this chemical is bitter, sour, sweet, or salty and to others it is tasteless.

Harris, et al. (4), have shown that rats can discriminate between diets containing and lacking vitamin B. Franke and Potter (3) demonstrated that rats were able to detect and differentiate between small quantities of selenium in foodstuffs.

Dove (2) from a long series of experiments with the rat, chick, and dairy calf concluded that nutritive instincts, manifested in a choice of food, are characteristics of the individual; that these instincts vary from individual to individual; and that these instincts are due principally to innate differences.

It is well known that animals possess a preference for foods derived from certain species of plants and it is also probable that differences exist among strains of the same species causing the expression of distinct preferences. The results of the observations and experiments with different genetic strains of corn reported in this paper suggest

that palatability or preferences exhibited by animals should also be considered in plant improvement.

SUMMARY

The results of feeding trials using genetically different strains of corn suggest very definitely that both mice and rats exhibit a preference for certain strains. One observation with swine also indicates a distinct preference.

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NOTES

GREEN NEEDLE GRASS, *STIPA VIRIDULA*, FOR EROSION CONTROL

GREEN needle grass, *Stipa viridula* Trin., is proving to be one of the most valuable native grass species for erosion control purposes in the northern Great Plains area. It grows under a wide range of soil and climatic conditions and appears to be extremely drouth resistant.

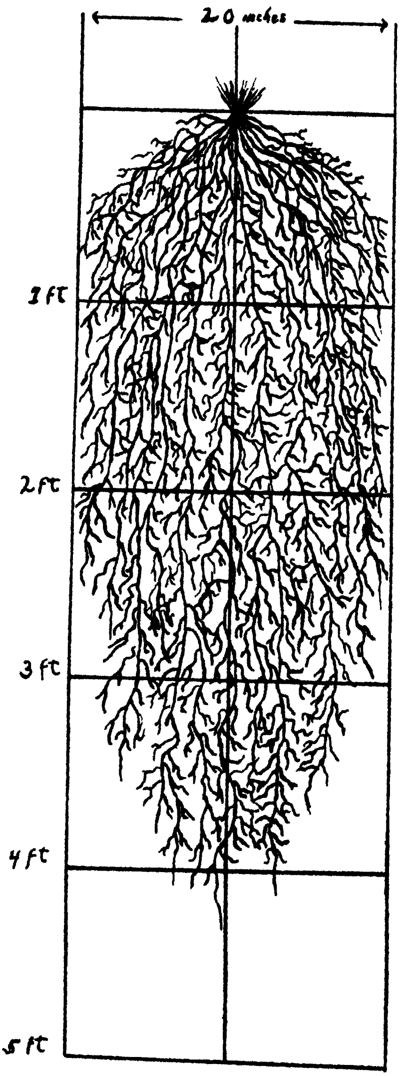

FIG. 1.—Root system of *Stipa viridula*.

It has been the opinion of ecologists that this species required a rather favorable habitat, being a local dominant in areas receiving more moisture. This conception may have occurred since it is commonly found, under natural conditions, in coulees, swales, and low spots.

In studying drouth survival of different grass species at various stations[1] in the northern Great Plains region during the past two years, *Stipa viridula* was found to have been extremely drouth resistant.

This species has a medium fine fibrous root system (Fig. 1) with a lateral spread of from 6 to 10 inches and a maximum penetration of about 50 inches.[2] Most of the roots are confined to the upper 36 inches. Being a bunch grass, *Stipa viridula* is not as efficient a soil binder as a sod-former.

Seeding and harvesting can be handled with the ordinary farm machinery. Planting can be accomplished with an ordinary grain drill. The seed should not be planted too deeply, from ¼ to ½ inch being recommended. To date, late fall or early spring plantings have given the best results. Seed can be harvested with a combine or stripper or cut with a mower and threshed.

[1]Ardmore, Brookings, Cottonwood, and Highmore, South Dakota; Dickinson Mandan, and Fargo, North Dakota; and Archer, Wyoming.
[2]From studies made in Kimball County, Nebraska.

Seed germination percentages are fairly high and the seedlings are extremely vigorous. They can withstand drouth and considerable sandblasting without serious damage.

The principal objection to this species is the uneven ripening of the seed on the panicle. The seed at the end ripens and shatters while that at base will still be green. No doubt this could be overcome through selection, thereby ultimately obtaining a strain or selection which would ripen the seed evenly. As with most native species, *Stipa viridula* shows wide variations in seeding and vegetative characters.

Palatability of *Stipa viridula* is high, being estimated at 70% by J. T. Sarvis of the U. S. Field Station, Mandan, North Dakota, and the U. S. Forest Service.—B. IRA JUDD, *Tempe, Arizona.*

A DEVICE FOR THE RAPID COLLECTION OF SURFACE-INCH SOIL SAMPLES

THE surface inch of soil on mountainous range watershed lands in the West commonly contains much more organic matter than do the deeper layers. Because this concentration of organic matter greatly influences percolation of water and because erosion losses are largely surface losses, it is essential in many range-erosion investigations that the surface inch (or at least a shallow layer) be isolated and evaluated.

A simple and inexpensive shovel device that facilitates the rapid and accurate sampling of the surface inch of soil has been developed by the Intermountain Forest and Range Experiment Station. This shovel will likely be found useful to many workers in the field who have experienced difficulty in obtaining surface samples with the conventional types of geotomes or augers ordinarily used for sampling soils.

The surface-inch sampler, as shown in Fig. 1, is made of sheet metal and the cutting edge sharpened. Automobile fender steel of 18 to 22 gage has been found well adapted for this construction and is sufficiently strong to withstand driving when necessary in dry soil.

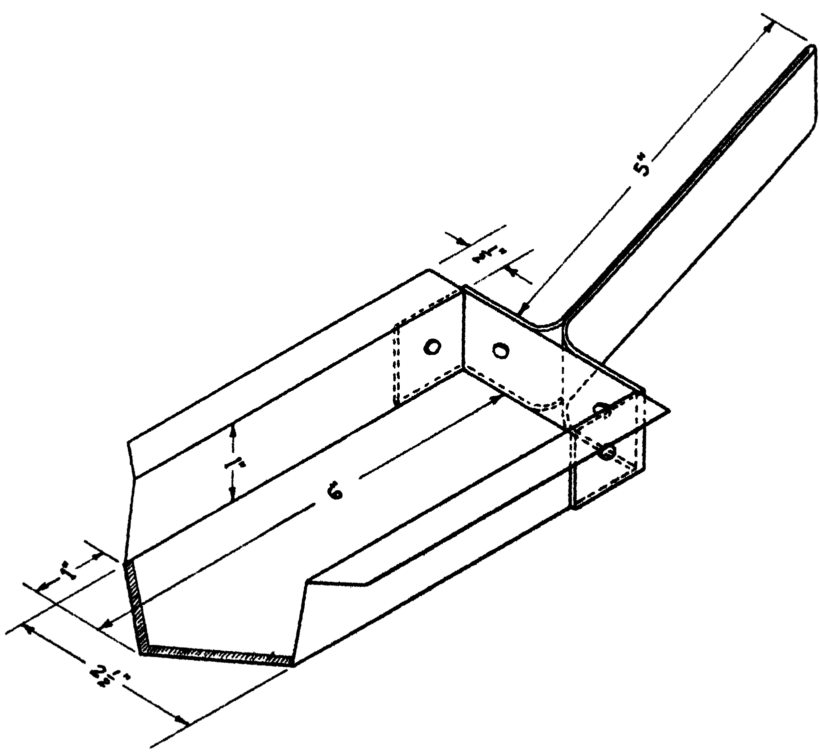

FIG. 1.—Diagram of hand shovel made of sheet metal for taking surface soil samples. The dimensions given are for surface-inch samples.

Samples are taken by pushing the shovel into a vertical cut in the soil in such a position that the projecting flanges are flush with the soil surface, thus removing measured surface-inch samples. By completely filling the shovel at each sampling, samples of approximately uniform volume may be secured. This allows representative composites to be made.

During the past season approximately 6,000 soil samples have been taken by the authors and other members of the Intermountain Forest and Range Experiment Station with this device. Analyses of these samples have given a clear-cut picture of soil losses caused by accelerated erosion. The use of the device also helps in getting uniformity of soil samples taken by different investigators.—LOWELL WOODWARD and D. A. ANDERSON, *Intermountain Forest and Range Experiment Station, Ogden, Utah.*

A SIMPLE MACHINE FOR CLEANING SMALL GRAIN NURSERY SAMPLES

AN efficient, inexpensive, and easily constructed seed cleaner, as shown in Fig. 1, is being used successfully for cleaning nursery samples at the Southern Great Plains Field Station, Woodward, Okla. The cleaner is almost mixture proof, having few places where a kernel may lodge and these being beveled and visible, the hazard of mixtures is minimized. The machine is easily and quickly adapted to cleaning different cereals by adjusting the position and speed of the fan and the slope of the metal plates. Three shakers, with screen bottoms of different mesh, for use with various grains serve to separate the coarser particles of straw from the grain, leaving mostly chaff and dust to be blown out by the fan.

Material to construct the cleaner will cost from $3 to $5, excluding cost of fan, the latter being available at most stations. The three shakers (Fig. 1, a), are fitted with 3/8-inch, 1/4-inch, and 1/8-inch hail screen. An 18-gage galvanized metal plate, held at any desired angle by thumb screw (Fig. 1, C), spreads the grain into a thin sheet and regulates the rate of fall. A second metal plate (Fig. 1, h), projecting any desired distance and angle, is held in place by thumb screw (Fig. 1, i) and aids in regulating the amount of material blown from the grain. Quarter-round is dadoed 1/4 inch above the pan (Fig. 1, n) to prevent kernels from falling beside or behind the pan. Two pans may be constructed to replace one another when re-cleaning is necessary. A three-speed, 14-inch electric fan is bolted to slide (Fig. 1, l). A thumb screw (Fig. 1, j) holds the slide at any desired distance from the box, thus further controlling the air passing through the box. A smaller fan might suffice for a box of this size.

In operation the grain is poured in at the top, the shaker is agitated by hand, the grain falls through the air blast, and the cleaned grain is removed in the pan (Fig. 1, n).—V. C. HUBBARD, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.*

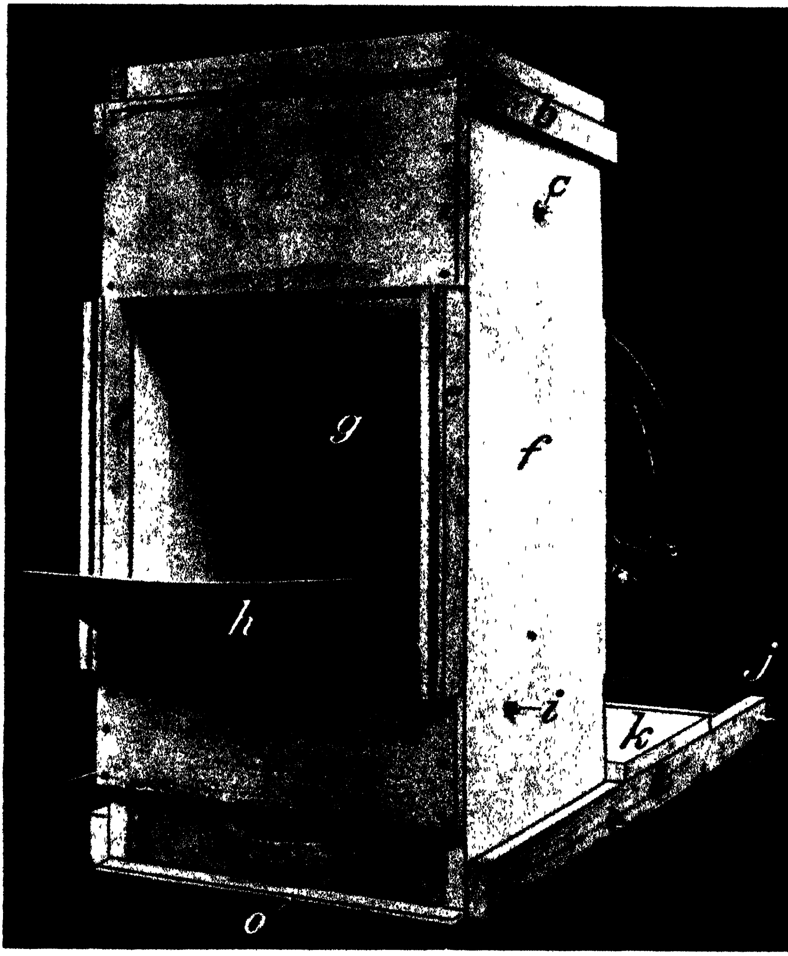

FIG. 1.—Machine for cleaning small grain samples. (*a*) Shaker, 1¼ inches deep and 11½ inches square; (*b*) 1 x 2 inch x 13¼ inch sides serve as guides for the shaker, *a*; (*c*) thumb screw, 4 inches from top and 6½ inches from the front of box, holding metal plate in place; (*d*) 1 x 6 inches x 13¼ inches; (*e*) 1 x 1⅝ inches x 12 inches (may be any width necessary to prevent kernels rolling off sides of plate); (*f*) side of box, 1 x 11⅝ inches x 24⅝ inches; (*g*) opening 11⅝ inches wide and 12 inches high; (*h*) 11 9/16 x 14 inch plate of number 18-gage galvanized metal enters box freely but snugly enough to be held in place by tightening thumb screw, *i*; (*i*) thumb screw, 6 inches from bottom and 4½ inches from box front (holds metal plate, *h*, projecting at any desired distance and angle); (*j*) thumb screw holds platform, *k*, in place (arms, *l*, are tightened on cleats nailed to under side of platform, *k*); (*k*), 11⅝ x 14¾ inch platform for supporting fan; (*l*) 1 x 1⅝ inch x 34 inch strips support and serve as slides for platform, *k*; (*m*) 1 x 4 x 13¼ inches; (*n*) pan of 18-gage galvanized metal. 2 1/16 inches high in front and 2 2/16 inches high at the back and 11¼ inches square (box opening for pan is 2⅝ x 11⅝ inches); (*o*) ¼ x 13¼ x 14 inches panel-board forms bottom of box and slide for pan (measurements of back of box are identical with those of front except that the bottom board, having no pan opening, is 1 x 6⅝ x 13¼ inches). Photograph by courtesy of L. F. Locke and E. W. Johnson, Division of Dry Land Agriculture, U. S. Dept. of Agriculture.

BOOK REVIEWS

POTASH DEFICIENCY SYMPTOMS

By Oskar Eckstein, Albert Bruno, and J. W. Turrentine. Berlin; Verlagsgesellschaft Fur Ackerbau M. B. H. 248 pages, illus. 1937. $2.25.

THIS book, representing the cooperative effort of the German Potash Syndicate, the French Potash Society, and the American Potash Institute, is designed to assist agriculturists in determining whether or not their soils contain a sufficient supply of available potash. Three languages, *viz.*, German, French, and English, are used in this volume.

A chart is given near the front of the book illustrating clearly the fact that such plant nutrients as nitrogen, phosphoric acid, and potash are removed from the soil in varying proportions by the different cultivated plants. Lengthy discussions are not included as it is realized that colored illustrations of potash deficiency symptoms in plant parts convey a clearer impression than words. The book presents the principal facts concerning plant abnormalities resulting from a lack of available potash.

The volume consists of two parts, *viz.*, general symptoms of potash deficiency, and potash deficiency symptoms on various cultivated crops. The first part deals with the external plant symptoms of potash deficiency as well as those modifications of the inner structure of the leaf, root, blossom, and fruit which result from a lack of potash. It also includes a discussion of the secondary effects of potash deficiency, such as its influence on the resistance of plants to diseases, pests, and unfavorable climatic factors. The second part describes in detail potash deficiency symptoms in maize, fruit trees, and vines, and contains many colored illustrations of characteristic potash deficiency symptoms in various cultivated crops. The volume contains a valuable study of deficiency symptoms, strikingly illustrated. (H. P. C.)

SOILS AND SOIL MANAGEMENT

By Charles Ernest Millar. St. Paul, Minn.: Webb Book Publishing Co. Ed. 2. 477 pages, illus. 1937. $2.

THIS revision, like its predecessor, is admirably designed as a stimulating text for elementary soils courses and for the lay reader who has more than a casual interest in the soil.

The book is copiously illustrated and each chapter is followed by a number of "Problems" based on the preceding subject matter. A list of pertinent references is also appended to each chapter. A glossary of technical terms encountered in the text, together with an excellent index, add materially to the usefulness of the book for the lay reader. (J. D. L.)

MOTHER EARTH

By Gilbert Wooding Robinson. London: Thos. Murby. VIII 202 pages, illus. 1937. 5/6.

THIS unique little book departs from the conventional form of book making to the extent that the seventeen sections of the text instead of being designated as chapters are termed "letters" on the soil addressed by the author, who is Professor of Agricultural Chemistry at University College of North Wales, to Professor R. G. Stapledon, Director of the Welsh Plant Breeding Station.

In terms intelligible to the general reader, the author attempts to set forth modern views on soils and their implications for present and future agriculture. "The affairs of the soil," writes the author in a preliminary statement to the "Gentle Reader", "may not have the strange magnificence of the outer universe or the curiosity of the inner recesses of the atom; but they touch our daily life more intimately," and it is the hope of the author that this book may aid the general public to think rightly on matters of grave concern to all—the future of the soil.

In a letter headed "Corruptio Optimi Pessima", the author deals briefly but comprehendingly with soil problems in the United States and the efforts that are being made to meet them. In the light of these problems he then proceeds to build up his hypothesis that the salvation of agricultural soils rests in the periodical renewal of their fertility under grass.

This book will be read with interest and profit by everyone actively engaged in soil conservation or seriously concerned with the future of the arable soils of the world. (J. D. L.)

THEORY AND PRACTICE IN THE USE OF FERTILIZERS

By Firman E. Bear, New York: John Wiley & Sons, Inc. Ed. 2. 360 pages, illus. 1938. $4.

THIS second edition represents a considerable revision of the first edition published in 1929. The chapters on nitrogen fertilizers, potash fertilizers, mixed fertilizers, principles of fertilizer practice, selection of fertilizers, application of fertilizers, controlling the soil reaction, and supplying organic matter have been largely rewritten. A new chapter dealing with the "trace" elements has been added. Changes and additions introduced involve consumption of fertilizers in the United States and Europe, availability and value of nitrogen carriers, equivalent acidity and basicity of fertilizers, calcimed phosphate, fertilizer recommendations for corn and cotton, tests for soil deficiencies, and selection and application of fertilizers.

The extensive studies and wide experience of the author in the fertilizer field are reflected in the character of the treatise. The field is well covered and still the book has been kept within reasonable size so that it may be used advantageously as a classroom text or by the busy practical or technical man. One might like to have the matter of reactions between fertilizer constituents and soil minerals discussed at greater length, especially in relation to fixation and soil reaction. The

material included has been well selected and arranged, and the method of presentation is clear and concise. The treatment is scientific but still quite understandable by the non-technical man. The brief historical treatment of the more important subjects should be stimulating to the thinking of both the student and man in practical work.

The book fills a real place in our fertilizer literature, and should serve as an excellent classroom text in many schools as well as a handy guide for the practical and technical man interested in fertilizer use. Apparently the editor failed to revise the paging in the table of contents so as to correspond with the changes in chapter lengths. (E. T.)

AGRONOMIC AFFAIRS

A DIGEST OF WORLD PASTURE RESEARCH LITERATURE

DR. A. J. Pieters, Principal Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, has compiled a digest of world pasture research literature exclusive of the continental United States and Canada. This supplements his digest of pasture research literature in the United States and Canada for the period of 1885 to 1935 already noted in the pages of this JOURNAL (Vol. 28, page 421).

The present Digest is in mimeograph form and contains 1,282 references arranged by country of origin. A list of abbreviations used in the citations and a subject index are included.

It is pointed out that the Digest does not purport to be a complete bibliography of pasture research literature outside the United States and Canada, but it is believed that enough is presented to serve as a cross-section of foreign pasture research of most interest to American students.

RANGE PLANT HANDBOOK

THIS Handbook, now obtainable from the Superintendent of Documents, U. S. Government Printing Office at $2.50 a copy, has been prepared under the supervision of W. A. Dayton, Senior Forest Ecologist, Range Forest Investigations, U. S. Dept. of Agriculture, primarily to meet the demand among field officers of the Forest Service for information on the identity of common plants on the national forest ranges, the value of these plants as forage for livestock and wildlife and as soil-binders in erosion prevention and control operations, and for concise information on range management.

The Handbook contains 841 pages of text and index, the latter also serving as a check list. There are 339 write-ups containing notes on about 300 "key" species and 210 genera of range plants, with secondary notes on over 500 additional species. The book is copiously illustrated, including 18 color plates. A unique feature is the tying in of a key diagnostic text description to each appropriate part of the plant in the illustrations, adding much to the usefulness of the latter.

NEWS ITEMS

ANNOUNCEMENT has been made of the appointment of Dr. E. C. Auchter, formerly head of the Division of Fruit and Vegetable Crops and Diseases of the Bureau of Plant Industry of the U. S. Dept. of Agriculture, as Chief of the Bureau of Plant Industry, following the resignation of F. D. Richey who is now engaged in professional corn breeding.

DR. S. F. THORNTON, formerly Soil Chemist at the Purdue University Agricultural Experiment Station, resigned that position on February 1 to become Agronomist for the F. S. Royster Guano Company of Norfolk, Va.

DR. GEORGE D. SCARSETH, Associate Professor of Soils and Associate Soil Chemist at the Alabama Polytechnic Institute, has been appointed Soil Chemist in the Agronomy Department of the Purdue University Agricultural Experiment Station, with the rank of Associate Professor, filling the position made vacant by the resignation of Dr. S. F. Thornton.

LEO D. WHITNEY, Assistant Agronomist of the University of Hawaii, died on November 7, 1937, following a brief illness. Mr. Whitney dealt chiefly with economic pasture grasses and also made notable contributions to the taxonomy of taro.

ERRATUM

IN Fig. 2 on page 14 of the January (1938) number of the JOURNAL in the article by A. N. Watson and R. L. Davis entitled, "The Statistical Analysis of a Spacing Experiment with Sweet Corn", the figures for "Total number per acre of marketable ears" on the left-hand margin of the chart are in error. These should read, from top to bottom, 2,400; 2,200; 2,000; 1,800; 1,600; 1,400; and 1,200.

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THE RELATION OF THE NATIONAL AGRICULTURAL PROGRAM TO AGRONOMIC BETTERMENT[1]

M. A. McCALL[2]

THE national agricultural program, developed at first under the Agricultural Adjustment Act and more recently under the Soil Conservation and Domestic Allotment Act, has reached further into the field of agronomy than most of us probably anticipated. What effect will its impacts exert in the betterment of agronomy itself?

The essential features of the A.A.A. program are generally known. Its objectives and its plan of operation are likewise familiar. Plans for 1938 operations have been outlined and discussed on our program during the current sessions of the Society. There is no reason, therefore, to go into these details, or to consider other than some factors directly important to us as agronomists.

The attitude of many agronomists toward A.A.A. activities has been that of the "innocent bystander." This rôle implies some curiosity and more or less mild interest. It is also pertinent to recall that the "innocent bystander" sometimes gets shot. This latter is mentioned merely to emphasize the fact that any enterprise as broad in scope and as active as the A.A.A. sooner or later may strike any one of us in a very direct way. It also has happened before now, in spite of "peace pacts," "neutrality acts," or what have you, that the "innocent bystander" found himself in the thick of things before he realized what had happened.

On the other hand, in the beginning there was good reason for the agronomist to feel somewhat detached from A.A.A. activity. The original avowed purpose of the program was to correct inequalities in farm income and to place the farmer on a more secure economic basis. It dealt with surpluses, crop adjustment and control, prices, income, and other economic factors. Its leaders properly were economists. We as agronomists have been sure from the beginning that agriculture can-

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Delivered at the general session of the annual meeting of the Society held in Chicago, Ill., December 2, 1937.

[2]Principal Agronomist in Charge of the Division of Cereal Crops and Diseases and Assistant Chief of the Bureau of Plant Industry.

not be brought to a stable economic status unless based on stable productive soils and sound crop practice, but most of us have had other things to do and it has been the line of least resistance to let it go at that. Probably as a result of detachment, many of us, also, have developed an attitude toward the problem and toward the economist strangely like that of the "pure scientist" toward his brother in applied fields. All of which proves nothing, except that as David Harum remarked, "The's as much human nature in some folks as th' is in others, if not more."

Subsequent developments, however, have so changed the original picture that now there is ample reason for a less detached point of view. The change began, in fact, very early in the program. Administrator Tolley of the A.A.A. in his report for 1936 says, "* * * the decision of the Supreme Court in the *Hoosac Mills Case* had the effect of hastening a transition which had long been planned. This was the transition from the temporary emergency phase of the adjustment programs to a long-time phase which would give a larger place to soil conservation and improved farm-management practice."

To us as agronomists, the significance of this shift and of the almost universal acceptance of wise land-use and soil conservation as a fundamental part of any long-time program to promote farm stability, cannot be over-emphasized. Both major political parties have recognized the principle in their platforms. It is one item upon which the farm organizations agree. Such general endorsement suggests that it will remain in the public mind as an essential part of any permanent Federal agricultural action program.

Soil conservation in its broad sense includes practically everything for which we agronomists have stood in the way of sound land and crop use, improvement, and management. Any activity that promotes universal recognition of soil conservation in this sense is making a real contribution to agronomy. None of us would credit the A.A.A. with discovering the importance of this kind of soil conservation in a stabilized farm program. On the other hand, I think we will all agree that the A.A.A., in focusing public attention on the necessity for soil conservation in developing farm economic stability, has made a most important contribution to agronomic betterment, the total extent of which only time can determine.

As agronomists, we naturally are interested in the direct tangible improvements in soil and crop management which have come about as a result of the A.A.A. program. A summary of the uses made of land diverted from surplus crops during the years of operation under the Agricultural Adjustment Act up to January 6, 1936, is given in the report of former Administrator Davis for 1933 to 1935. There were 35,767,899 acres shifted from the production of cotton, corn, wheat, and tobacco in 1934, and 30,336,838 acres in 1935. Studies made in 1934 showed that a majority of Corn Belt farmers used this diverted acreage for establishing alfalfa; sweet clover, and timothy, or elected to use old sods as contract acreage, allowing them to lie unplowed. Estimates for Ohio, Indiana, Illinois, Iowa, Missouri, and Nebraska showed that in these states 9,264,698 contracted acres were used approximately as follows:

"About one-third for new seedings of meadow and pasture crops, chiefly alfalfa, sweet clover, and clover and timothy.

"About one-fourth in old meadow crops left unplowed (clover, timothy, sweet clover, bluegrass pasture).

"About one-third planted to emergency forage crops (soybeans, millet, Sudan grass, forage sorghums, fodder corn).

"About one-twelfth, used for controlling weeds, was fallowed or left idle."

Data for 1936, the first year of A.A.A. operations under the Soil Conservation and Domestic Allotment Act, are given by Administrator Tolley in his 1936 report. In presenting the data, attention is directed to the fact that the Act was passed at too late a date to allow many farmers to participate, and too late to permit adequate farm planning. The drouth of 1936 also affected the program. The following paragraph is summarized from the report:

More than 283,000,000 acres, or 67% of the crop land in the United States, was covered by the program. In the soil-building and conservation program, legumes were sown alone or in mixtures on 33,578,157 acres; pasture was established on 1,704,198 acres; green manure crops were grown on 7,597,729 acres; forest trees were planted on 22,052 acres; mechanical erosion controls were carried out on 5,027,380 acres; limestone, phosphate, and other chemical fertilizers were used on 3,220,251 acres; orchard improvements were made on 37,046 acres; and miscellaneous practices were applied on 1,825,805 acres. In all, soil-building and conserving practices were put into effect on 53,012,618 acres.

The above are interesting data as giving a picture of the scope of the program and the acreages involved. There is no certain way of determining from these data, however, the extent to which the tabulated results represent departures from and improvements in the usual practice of the country as a whole. The use of diverted acreage for these purposes implies a change to the amount of the diverted acreage. However, since all farms were not in the program, the possible opposing shifts of non-cooperators are unaccounted for. The fact, as stated in former Administrator Davis' report, that existing plantings of meadow crops were included in contract retirements also obscures the total accomplishment. In measuring the success of the program in promoting soil conservation in the country as a whole, it is necessary, therefore, to consult other data.

The best index of accomplishment in a soil-building and soil-conserving program should be the changes in acreages of grasses, annual and perennial legumes, green manure crops, etc., and in lime and fertilizer sales. The most convenient data for indicating crop changes are those collected by the U. S. Dept. of Agriculture. Unless otherwise indicated, data from this source are the basis for the following summaries.

Unfortunately, these data do not show all that may have been accomplished by the A.A.A. program. For example, there are no data available on pasture acreages, except those from the census, and these are useless for the need at hand. Neither are there data on grasses, other than timothy, or on green manure crop acreages. In addition, the crop data are not sufficiently refined and are too much affected by

drouth and insect damage to give a fair picture of original sowings and hence of the complete operations of the program itself. Recognizing these deficiencies, it is felt, however, that trends may be shown and some measure of accomplishment may be arrived at even though not complete in all phases. Granting this, there may be some question as to how much credit should be given to any one agency for such changes as may be noted. The state agricultural experiment stations, the state extension services, and agencies other than the A.A.A. in the U. S. Dept. of Agriculture, all have been and are urging the various measures which the data should reflect. It seems fair to assume, however, that any significant modifications in line with the active recommendations of the A.A.A. can be attributed properly in part to that agency.

Soil conservation features have been given some emphasis during the entire A.A.A. program, so that it seems proper to consider the entire period of the program in a survey of its accomplishments. Emphasizing limitations, a survey of certain key crops follows.

Alfalfa is a basic crop in any extensive soil-building undertaking. The alfalfa acreage during recent years has shown a steady year-to-year increase, except for slight drops in 1934 and 1936. The increases during the years of A.A.A. activity have been greater than in any similar period. These occurred in spite of drouth and grasshopper damage, which undoubtedly caused the loss of some young alfalfa sowings as was true of similar crops. The national annual harvested area during the period 1928–32 averaged 11,720,000 acres. In 1937 this was increased to 13,787,000 acres, which, however, because of the 1936 drouth, was 359,000 acres less than the 1936 acreage. State acreage data for 1937, covering the 10 states of Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Kentucky, and Tennessee, showed a combined increase of 2,885,000 acres over the 1928–32 average. This was greater than the total national increase, being balanced by a decrease in the irrigated West. Because the increase in the alfalfa acreage was substantially above that for any similar period, and this in spite of the drouth, it seems reasonable to attribute at least the accelerated increase to the A.A.A. program.

The acreage of sweet clover harvested as hay shows some increase, although nothing approaching that of alfalfa. Interestingly enough, the acreage of sweet clover has tended to remain more or less stationary or to decline in those states where the principal increase in alfalfa has occurred. It has shown a substantial increase in Wisconsin, Minnesota, and North Dakota. In these three states the combined annual average area for the period 1928–32 was 410,000 acres. In 1936 the total was 767,000 acres. National totals for comparison were 866,000 and 1,100,000 acres, respectively, showing a decline elsewhere than in these states. Considering the fact that the sweet clover acreage has shown no marked changes since 1929 other than a slight gradual decline up to 1935, it again seems reasonable to attribute the increase which has occurred during the latter period of A.A.A. activity to that stimulus. In the states where the increase has occurred, it is significant.

The acreage of lespedeza cut for hay also has shown a marked

increase during the period of A.A.A. activity. There was a regular increase each year up to 1936 when there was a sharp reduction, with restoration to the previous top again in 1937. The acreages for the individual years beginning in 1932 and ending in 1937 were 1,115,000, 1,701,000, 1,578,000, and 2,036,000, respectively. The widely grown lespedezas are annuals, and the acreage reduction in 1936 reflected the severe drouth of that year. The Division of Forage Crops and Diseases of the Bureau of Plant Industry estimates that 25,000,000 acres of lespedeza are used for pasture. A number of agencies have claimed credit for the increase in lespedeza production, including the editor of a widely circulated farm journal. There would seem, however, giving everyone his due, to be glory enough for all, and reason to believe that the A.A.A. program should receive a substantial part of it.

Data on clover acreages are the most unsatisfactory of any from which to draw conclusions as to A.A.A. contributions. Because a considerable acreage of clover is grown with timothy, the Crop Reporting Service groups all clover and timothy together. With a decreasing horse population there has been a downward trend in the acreage reported under clover and timothy since 1924, when the total stood at 34,038,000 acres. This reached a low of 20,146,000 acres in 1934 and built back to 22,034,000 acres in 1936. This would suggest a check in the downward trend and some restoration. Any gains, however, were entirely lost as a result of the 1936 drouth with attendant loss of plantings, the 1937 acreage setting a new low of 19,481,000 acres.

The influence of drouth losses on the clover and timothy acreage is shown by the record of a few typical states. Combining the acreages for Ohio, Illinois, and Iowa, where trends were the same, the 1928–32 combined average was 5,985,000 acres. In 1935, following the 1934 drouth, there were 4,061,000 acres. In 1936, following a more favorable season in 1935, there were 5,038,000 acres. Following the drouth of 1936, this was reduced to 3,408,000 acres, which, with the decrease in the national total from 22,010,000 acres to 19,674,000 acres, shows a trend similar to that following 1934.

The drouth of 1936, following a series of bad years, not only affected the amount of current sowings and their survival, but also seriously reduced the seed crop. As a result, seed prices were high for 1937 sowings, particularly for red clover seed. A survey made by the Division of Hay, Feed, and Seed of the Bureau of Agricultural Economics shows that in the section of the retail trade covered by the survey, sale volumes of red clover seed were essentially the same for the years 1934, 1935, and 1936. Prices for these years averaged $14.75, $23.65, and $20.90 per hundred, respectively. In 1937, with an average price of $38.25 per hundred, the sale volume was only 72.5% of the average volume of the preceding three years. Moreover, the smaller amount of seed available for sale also contributed to reducing sales volume and presumably sowings. Actual data on sowings are not available, and it is necessary to wait for the 1938 acreage data to determine the real total effect.

The foregoing survey of clover and timothy acreages, and of factors influencing trends, indicates how nearly impossible it is to determine the true effects of the A.A.A. program on the basis of the end results

for these crops. There is some suggestion of a positive effect indicated by the increased 1936 acreage following improved conditions in 1935. The data do emphasize, however, the generally unfavorable seasonal sequence under which the A.A.A. program has been operating, and suggest that better results may be expected under different circumstances.

Of the annual legumes, soybeans have made the most phenomenal increase. In 1937 the total area in soybeans grown for hay and seed was 5,996,000 acres, as compared with an average of 3,024,000 acres for the period 1928–32. The 1937 acreage shows an increase of 613,000 acres over the 1936 acreage. Of the total 1937 crop, 3,659,000 acres were cut for hay, as compared with 3,251,000 acres so harvested in 1936, and 2,149,000 as an annual average during the 5 years, 1928–32. There has been an increase in the use of soybeans as hay, which has been encouraged by the A.A.A. The need for an annual legume forage because of perennial legume seedings lost by drouth, and the remarkable drouth resistance of soybeans during 1934 and 1936, have played their part in promoting increased soybean forage plantings. Granting this, it would seem that the A.A.A. should receive its share of credit for the increase.

Under the A.A.A. program, the acreage of cowpeas has nearly doubled, building up from an annual average of 2,301,000 acres for the 5 years, 1928–32, to 3,624,000 acres in 1937. The acreage cut for hay during the same period increased from 1,502,000 acres to 2,237,000 acres. This increase seems rather definitely tied up with the A.A.A.

The A.A.A. has also operated effectively in promoting crop improvement, as shown in the present situation relative to red clover seed of foreign origin. Following the drouth of 1936 with its attendant serious reduction in the seed supply of adapted domestic strains of red clover, there were heavy importations from foreign sources. Experimental data show that these foreign strains are not adapted in many parts of this country. Based on these data and on farm experience, the A.A.A. placed a regulation in effect providing that soil-building payments could be made for clover plantings only when adapted seed was sown, and defining adapted seed as that of domestic or Canadian origin. This ruling probably did more than any other step ever taken to impress on farmers the meaning of adaptation and its importance. Its effects are likewise evident in the much reduced scale of importation during the current importing year in spite of continued shortage in the clover seed supply. One prominent European seed merchant, relying on the short supply in this country, set up special offices in Chicago to handle his import business. Demand was so limited that he closed out and left early in the season. Those interested in clover improvement in this country feel that this move, by preventing excessive dilution of domestic stocks with unadapted foreign strains, in the end will be of marked benefit, even though it may reduce current sowings and present total acreage.

The use of agricultural lime and of fertilizer materials should be a direct reflection of success in a soil-building program. The National Lime Association estimates the use of ground limestone and other lime

materials at 3,736,367 tons in 1929, 3,498,296 tons in 1930, 2,548,941 tons in 1931, 1,839,715 tons in 1932, 1,627,057 tons in 1933, 2,433,841 tons in 1934, 3,291,789 tons in 1935, 6,305,426 tons in 1936, and somewhere between 7 and 8 million tons in 1937. In 1936 the total exceeded 4,000,000 tons for the first time in the history of the industry. This remarkable increase in the use of agricultural lime, centering as it does on the period of the A.A.A. soil-building program, can hardly be attributed to any other factor than that activity. This is one of the most significant measures of accomplishment by the A.A.A.

Fertilizer use likewise shows a strong upward trend during the period from 1933 to 1937. The National Fertilizer Association reports that from a low of 4,335,607 tons in 1932, their record shows a consumption of 4,871,271 tons in 1933, 5,547,520 tons in 1934, 6,220,831 tons in 1935, and 6,820,193 tons in 1936. According to the *Fertilizer Review* of September-October, 1937, the 1937 consumption will probably total about 8,250,000 tons.

The increase in tonnage has been accompanied by an increase of the average plant nutrient content in the fertilizers used in many parts of the country, which adds further significance to the figures given. A summary of fertilizer consumption in the United States, issued by the National Fertilizer Association in August 1937, shows that there has been an increase in the weighted average nutrient content of mixed fertilizers consumed in the country as a whole from a low of 13 9% in 1920 to 18.2% in 1936. This increase has varied for different parts of the country, being greatest for the Northeast and West and least in the South. In 1934 the average nutrient content for all fertilizers used in the South was 16.77% compared with 23.09% for New England, 20.87% for the Midwest, and 20.78% for the Far West.

In this same report is a highly significant statement on the relationship of agricultural purchasing power to fertilizer use which is worth quotation. It is as follows:

> "Over a long period of time the total amount of fertilizer used will depend largely on the plant-food deficiencies in soils and the technological developments making possible the furnishing of these plant foods through the application of chemical fertilizers. Year-to-year changes in fertilizer tonnage, however, are determined primarily by economic factors as distinguished from agronomic or scientific factors. Whether the volume of fertilizer used this year is larger or smaller than last year's tonnage does not depend to any appreciable extent on changes in plant food deficiencies in the soil or on industry's ability to manufacture fertilizers to supply these deficiencies. It depends, rather, on changes in the financial ability of the farmer to buy fertilizer. If prices of farm products are higher than a year ago, if crops are good, and if fertilizer prices are regarded as reasonable, it is quite likely that tonnage will be larger.
>
> "It follows that farm income is the best available single indicator of the demand for fertilizer and of the farmer's ability to buy it."

This statement, based on an analysis of fertilizer sales and farm income in various parts of the country, makes clear one reason why the A.A.A. program should be credited with a substantial rôle in increased fertilizer sales. It also emphasizes the fact that the advancement of all sound agronomic practice is intimately associated with

economic prosperity and stability. Sound agronomy is dependent on sound economics, just as sound economics is dependent on sound agronomy. The two cannot be separated.

In addition to the above-noted direct contributions to agronomic betterment arising from the A.A.A., there are others more indirect, yet probably in the end equally or even more significant. As a result of the A.A.A. program, every important agricultural county in the United States now has a county agent. The farm people of each county have come to know and to rely upon their agent and to use his services as never before. The number of his contacts and his effectiveness have been immeasurably increased because of the program. This must in the end have a profound effect upon agronomic improvements.

Another most significant development is the County Agricultural Conservation Association with its county-planning committee. This committee in each county is charged with administering the program and with working out through community committees a balanced soil-building and cropping program for the county, which in turn must be based on a soundly developed plan for each farm. In some states substantial progress already has been made in farm planning and productivity surveys, which ultimately are certain to be strongly influential in building a sound agriculture. These county committees should become increasingly important in the agricultural set-up in each state. They should become a most effective link in the chain of agronomic improvement.

Other examples of the effects of A.A.A. impacts on agronomic betterment doubtless could be pointed out. Enough has been indicated through the foregoing somewhat superficial survey to show, however, that the A.A.A. has contributed, and is contributing, in a very substantial way to advancements in soil conservation and crop practice. It is without question a most potent force for implementing soil and crop science. It adds a new element to the previously existing set-up of the state experiment stations, the extension services, and the research bureaus of the U. S. Dept. of Agriculture. Most of us have failed to realize the real necessity for this new element. We have prided ourselves that agronomy is so necessary and so universal that we and our work are removed from the fields of controversy that rage round all economic problems. In reality these notions have been "delusions of grandeur." Sound agronomy is dependent on and cannot be separated from sound, stabilized economics. Combining the two, the A.A.A., program carries a challenge we cannot avoid.

INTEGRATING RESEARCH AND EXTENSION IN AGRONOMY[1]

R. D. LEWIS[2]

IN EVERY field of scientific endeavor epoch-making discoveries and rapid accumulations of knowledge have given rise to tremendous problems of fitting the segments and elements into unified and usable systems of action. A layman's casual inspection of the proceedings of various societies and organizations indicates that the topic of "integrating" must truly be a perennial that often buds but seldom discloses the wonders of the blossom! Nor would I lead you to anticipate herein any striking floral display of integration of research and extension in agronomy.

To some the integrating of research and extension in agronomy may be evident both as to desirability and as to methods of accomplishment. Yet any discussion of integration may easily become a series of trite, speculative, vaguely general phrases, and be neither factual nor quantitative. At the start may I note that although this discussion is limited to integration within the field of agronomy, I am quite aware of the tremendous responsibilities that confront research and particularly extension in the correlation of knowledge and activities from all fields that affect the farm family, its home, and its enterprises. Would we not be presumptuous to assume that we are qualified to solve these larger problems, unless we may first effect a greater degree of integration within our own field?

Pasteur gave us a simple but forceful expression of the significance of integrating research and extension when he wrote, "What really leads us forward is a few scientific discoveries and their applications." We are all familiar with the functions of the researcher in agronomy in making discoveries, organizing knowledge, and creating materials, but are we aware of the functions of the extension agronomist? The extension agronomist is the interpreter, the teacher, the correlator of those facts and processes that seemingly may be incorporated into scientific systems of soil management and crop production. His work is going through significant transitions. Formerly the extension agronomist was largely concerned with getting to more farmers the information and practices that were already in use by a few of the leading farmers, who may or may not have acquired the practices as a result of formal agronomic research. This type of extension will and should continue. But with the rapid development of knowledge and creation of new materials, the extension agronomist must concern himself with methods of transmitting these results of research quickly, effectively, and properly balanced for fitting into the agricultural

[1]Contribution from the Department of Agronomy, Ohio State University, Columbus, Ohio, and the Bureau of Plant Industry, U. S. Dept. of Agriculture. Also presented as part of the general program of the annual meeting of the Society at Chicago, Illinois, December 2, 1937.

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programs of many people. Extension is simply a method of teaching, a tried and proved method that had effectively reached hundreds of thousands of rural adults and youths before formal educators even recognized that such teaching was in existence!

To facilitate progress in this discussion, I make certain assumptions that to me seem self-evident. In the first place, research and extension in agronomy have, in general, a common objective—the improvement of rural life through the discovery, organization, and correlation of our knowledge of the physical, chemical, and biological processes in soils and crops into scientific systems of soil management and crop production. Secondly, the granting of public funds to us for the advancement of knowledge and the creation of materials raises responsibilities for incorporation of the knowledge and materials into programs of action and living. More and more, research as well as extension is concerned with the effects of science and its applications upon the individual and his society.

In the third place, the transmitter of science—specifically, the extension agronomist—must realize the probability that action will be taken upon recommendations he makes. It was only a few years ago when he often wondered if anyone would accept those recommendations—now, he must constantly think of the results of large groups accepting them. These three basic considerations leave us no alternative—we must give more thought to the integrating of research and extension.

May I emphatically dismiss any interpretation of the foregoing remarks that might seem to minimize the fundamental values of pure or abstract research. From such springs of knowledge come elements that will eventually be incorporated into highly significant practical developments. As a witness to this I cite the 30 to 50% of the acreage of the Corn Belt that will be planted with corn hybrids in 1938—the direct outgrowth of pure research in the early 1900's, which in turn was based on the researches of Mendel in the 1860's.

If we grant that there should be more "integrating" of research and extension in agronomy, we may logically inquire, "Why don't we have more of it?" and "What situations tend to hinder integration?" May I catalogue a few of these situations? My list concerns mostly the human elements. Many of the hindrances are due to mutual lack of knowledge and appreciation on the part of research and extension workers (3)[3].

We often note the reluctance of certain research workers to assume interest or accept responsibility beyond the scientific discovery. The process of discovery seems to give far more satisfaction than the attainment of use. The attitude which says, "I've found it! That's enough for me!" reminds one of the college student returning from a date late at night only to be questioned by his roommate: "Come, tell me about it?" "Well, I called for her in a taxi, took her to dinner, and then to a dance, and home again in a taxi." "Did you kiss her good-night," pried the roommate. "Why, no," said the future scientist, "I had done enough for her for one evening."

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[3]Figures in parenthesis refer to "Literature Cited," p. 187.

While modesty may result in reluctance to assume responsibilities beyond the discoveries, both research and extension would be strengthened if more energy were applied to interpreting the scientific findings to the extension workers. Some of this modesty of the researcher in his relations with the extension agronomists may at times be due to lack of knowledge and appreciation of extension as a method of teaching and a means of getting research results before those who may use them. Some research agronomists of high ability isolate themselves too much. This isolation sometimes leads to inaccurate determinations of the nature of specific soil or crop problems and to the neglect of relationships with other problems.

Now the extension agronomist often works under severe handicaps that hinder the process of integrating research and extension. Frequently, he is not well enough grounded in knowledge, scientific discipline, and in the use of scientific methods. Because of these situations, he may tend to analyze incorrectly cause-effect relationships which might be readily interpreted by applying simple basic principles of soil or crop sciences. He often tends to accept, as fact, observations not based on measurements or thorough examinations of causes.

But, we must realize that every extension agronomist has so many immediate and expedient activities thrust upon him that it generally becomes impossible for him to drive toward a clear-cut objective. He is primarily a man of action, who has little time for reflection. If he is so fortunate as to possess the habit of reflection and at the same time to be a man of action, his work will be outstanding.

As both research and extension workers in agronomy tend to be distinctly human, individuals in both groups are subject to certain common hindrances toward integration of their efforts. Unfortunately, we are at times prone to take up the cudgels against another worker and his ideas rather than to push forward toward the solution of the common problem. Yes, of course, we make progress by "showing up" another agronomist, but at times that progress is needlessly obscured by the smoke of the battle!

Both research and extension workers should have a greater awareness of what the scientific method in action really involves. Our thoughts along this line were greatly stimulated a few years ago by a careful exposition of the elements involved in the "engineering approach". At the conclusion of the exposition someone ventured to inquire of the engineer leading the discussion, "Is not the 'engineering approach' you describe the same in procedure and spirit as what is commonly termed the scientific method—analysis, formation of hypotheses, and testing?" Our engineering friend replied, "One more element must be added to the scientific method for it to become the engineering approach—there must be action. The engineer does something about it." And without quibbling over terms, we in agronomy may well be more active in integrating research and extension.

Both research and extension workers in their enthusiasm for their own findings and projects often neglect to correlate their activities and the applications of their findings and teachings with others in the

same or related fields. Consequently, our work is often needlessly duplicated or at least not properly integrated into a usable and balanced system.

I have often been disturbed by those hasty appraisals that set off individuals as being of the "research" type or of the "extension" type. Too often such appraisals imply that since a given individual is not of the research type, he can be automatically classified as a suitable extension worker. Now, I am fully aware that agronomists can be divided into types—some of us are abstract researchers, or prefer a cloistered life, or just do not like to work intimately with other people in interpreting our findings. But I do plead that in the fundamental spirit of scientific approach to problems, research and extension agronomists shall be alike. A certain man had identical twin sons. He determined to test out the much-disputed Harvard versus Yale traditions and educational systems, so he sent one of the twins to Harvard, the other to Yale. At the completion of their college careers, the father observed to a friend, "John came back from Harvard, a gentleman—and Henry came back from Yale, but still I couldn't tell them apart". And likewise there should be a common bond of spirit that identifies all workers in our field primarily as agronomists, whether or not they happen to be in research or in resident or extension teaching.

The very nature of their respective public services often results in extension over-shadowing research, but the remedy for this lies in the complete recognition of the fundamental relationships between the two fields (2). Planned integration of research and extension in agronomy will bring to the public greater awareness of the basic source of extension teachings and materials—research.

Many significant illustrations of the integrating of research and extension in agronomy are to be found today. Such cases are multiplying. I cite three of them which involve different basic situations. I shall confine these illustrations to projects in Ohio, simply because I know something of the underlying conditions and philosophies.

The Ohio research-extension program for the development and utilization of adapted corn hybrids is an integrated program, founded on the direct usage of ideas and materials created by research. The objectives and the basis for this program were laid in 1932–33 in numerous planning conferences of the research and extension workers in corn improvement. In 1937 this planned program had been developed to the point where 260 growers produced commercial supplies of seed of adapted hybrids and a group of 320 apprentices gained experience with 1/8 or 1/4 acre crossing plats. By 1937 seed production had been initiated in each of the 88 counties of Ohio. Practically all of the producers are graduates in 1933 or later of that portion of the integrated program which provides education and training for apprentice producers and widespread trials of promising new hybrids.

In developing this program certain fundamentals have guided the cooperating research and extension workers. The ultimate objective has always been the making available of reliable seed of adapted hybrids at a price consistent with the best interests of both producer and user. The research and extension institutions accepted responsi-

bilities to see that effective use be made of created materials. A small beginning was followed by a steady growth toward wide participation. This participation was initiated on an experimental and educational basis through the apprentice system. The prospective small-scale producer of interest and ability has been given the same initial opportunity as the larger producer. Close contact with the growers has been maintained through informational news letters, circulars, special training schools, individual visits, and a formal inspection and certification system. For instance, the number of mimeographed news letters and circulars on instructions and procedures exceeded 60 during 1937.

Thus, a trained and cooperative group of producers has been developed for the production first of commercial hybrids and then of foundation seed stocks. In the earlier stages of the program, the cooperating research and extension services accepted the responsibility for the production and distribution of foundation seed stocks of single crosses. In 1937, after a trained personnel had been developed through the integrated program, we assisted a cooperative group, representing a large majority of the producers, to initiate a seed stocks producing organization which will continue to assure reliable foundation seed stocks to small as well as large producers and make possible the continued correlation of production, distribution, and use of such seed stocks (1).

In this cooperative hybrid corn program there has been a direct and unbroken current of ideas and materials from research through extension to seed producer and seed user. The research program has been influenced by the interrelationship; all significant steps in the extension phases of the program have been taken in accordance with the underlying research information. Policies and problems have been solved by cooperative thought and action and those closely interrelated have at no time been separated into distinct research and extension functions. Undoubtedly a major factor in this orderly development was that the participating research and extension workers were well trained in the fundamentals of modern plant breeding.

Incidentally may I note here that integration in our hybrid corn program has extended beyond our state, for there has been no reluctance on the part of the research and extension workers in corn improvement to make effective use of inbred lines and hybrids developed elsewhere. The sole determining factors have been performance and the availability of reliable seed stocks.

Another type of integrated program, which I call the interplay or reversible exchange type of integration, is illustrated by the research-extension projects on methods of seeding meadows in Ohio. Type, extent, and regularity of meadows are the outstanding constructive factors in the conservation and improvement of the productive capacities of Ohio soils. Why then do we not have more uniformly good meadows? The difficulties of obtaining good stands of forages seem to be the bottle neck of the problem. Any program for increasing the proportion of land in soil-building sod crops must first of all attack the problems of obtaining seedings.

From research and extension work in this field agronomists began to develop in 1932 tentative outlines of the factors involved in obtaining successful stands of legumes and grasses. Existing information was fitted into appropriate places within these outlines, and the research men directed further experiments toward filling in the weak points in our knowledge of seeding methods. At the same time the extension agronomists, aided by a series of lantern slides provided by the investigators, conducted further discussion groups with farmers. From each of these meetings came suggestions as to investigations or methods of research and extension approach to the problems. Naturally, both research and extension approaches were modified by these interchanges.

As a result of these interchanges of experiments and experiences, there was finally developed in 1936 a chronological outline of the more important causes for failures to obtain stands of meadow crops. Methods of counteracting these causes were organized into workable, practical, and successful systems of seeding meadows. Causes for failure, seeding and management technics designed to counteract these causes, and the organized systems of seeding methods have now been collected into a bulletin recently published by the Ohio Experiment Station on "Better Methods of Seeding Meadows" (6). Curiously enough portions of this bulletin, summarizing the methods of obtaining better seedings under the three most frequent situations obtaining in Ohio, were incorporated into mimeographed extension circulars and presented by discussion and lantern slides to numerous farm groups well ahead of formal publication of the bulletin.

It is evident to those of us who have participated in this reversible action type of integration that research and extension have profited both as to fundamental knowledge and as to methods of organization and presentation.

The two preceding illustrations of the integrating of research and extension in agronomy have originated in specialized activities with a single crop, corn, and with a group of meadow crops. Such activities, of course, represent only segments of a complete and balanced program in agronomy. However, there is small likelihood of our approaching either completeness or balance unless these segments be so constructed that they can be fitted into their proper places in a synthetic approach to the larger problems of agriculture. Inferior workmanship or quality of materials in the smaller segments will but weaken or mar the structure we hope to build.

And we shall not be permitted to play forever and alone with the individual blocks or segments. While there may have been a tendency in the past to advance improved practices more or less independently, it would seem that the progress made in agronomic knowledge, materials, and approaches should now justify more attempts by research and extension agronomists to weave together significant systems of soil and crop management. Nor can integration be confined within agronomy. In both research and extension we note that correlation and integration are cutting across subject matter lines whenever the attainment of desirable objectives can be facilitated by

bringing the thought and action of various interest groups to the attack of the underlying problems.

In common with agronomists of other states, we in Ohio have attempted to develop a systematic approach to the use of land on individual farms. We have brought together information from researches as a basis for analyzing what the net effect of a given system of soil and crop management may be on the productive ability of soil.

We have dared to suggest and use simple mathematical expressions by which the effects of individual crops and soil practices upon soil productivity might be approximated—both to facilitate analysis of existing systems and the synthesis of more desirable systems. As this method of integrating the segments of soil and crop management into a combined and simple expression has been fully presented elsewhere (5) and discussed by a former president of this Society (4), I desire to point out here something of how the system came into use and how it is effecting a greater degree of integration within agronomic activities in our own state.

In 1932 the need for indexes that would evaluate, at least approximately, the effects of individual crops and of various soil practices was expressed in a conference of the research and extension agronomists. At the Experiment Station studies had been progressing on changes taking place in the soils over periods of 35 to 40 years. In 1933, research-extension agronomists suggested tentative productivity indexes for certain crops as a possible basis for payments on contracted areas under the Agricultural Adjustment Administration. In 1934, these tentative indexes were found to be highly valuable in simplifying the appraisals of corn lands. A year later, the research-extension agronomists were confronted with the problem of analyzing the effects of existing generalized cropping systems on the productive abilities of Ohio soils and suggesting regional changes that should be made to conserve and improve these productive abilities.

Accepting the challenge, research and extension agronomists examined again the foundations for the productivity index system of analysis and synthesis. We recognized imperfections and discovered many places where fundamental information was lacking or meagre. The indexes were refined and used as a basis for the studies on regional agricultural adjustments in Ohio. In 1935 and 1936, the same indexes, appropriately modified for such factors as erosion, use of manure and fertilizer, etc., provided the basic method of analyzing the generalized soil and cropping system of each county in the state. During the past two years, thousands of Ohio farmers have examined practices on individual farms and have started to reorganize their individual soil and cropping systems. On these individual farms the "productivity balance" is obtained by weighing each crop and soil practice according to its probable effect on soil productivity. By setting the favorable factors collectively against the unfavorable ones, a net result called the "productivity balance", is derived. This balance is a collective expression that includes the chemical, physical, and biological resources of the soil concerned. This method of approach has enabled individual farmers to grasp the nature and effect of the cropping

systems and soil management practices that they have been following and they have thereby discovered the weak points.

This is only one of a possible series of illustrations of integration of segments into a workable system that have been developed by correlation and integration of research and extension. Needless to say, such an approach has had a profound effect upon research programs in agronomy and in related fields. The agricultural economists have demonstrated by field surveys of actual farms during 1936 and 1937 the validity of the productivity index method of approach and have found a high correlation between productivity balances and farm income. In the field of extension agronomy, the application of individual improved practices assumes new importance as we are enabled to see more clearly how specific practices fit into the system with which the farmer deals.

So much for the past! Let us look briefly at the future.

Every agronomist could cite cases where present and future research activities raise the necessity for a planned integration of research and extension. We will probably trend toward accepting greater responsibilities for originating and directing, at least during the development stages, successful method of utilizing the out-turns of research. May I cite two examples of the developing need for integrating research and extension?

The first example concerns the general problem of adaptation of seeds of farm crops. "By their performance you shall know them" is still a long way from wide realization in farm practices with seeds. There is too little appreciation of the significance of the fundamental factor of heredity in determining adaptation and performance. If you are skeptical of such a statement, go among groups of farmers and even examine comparatively recent statements and writings of some agronomists relative to the alleged significance of various ear characters in forecasting yield in corn. And these reactions exist in spite of 30-year-old research by agronomists and several symposia on the subject before this Society! Yes, we have come a long way in the past 25 years in utilizing the out-turns of modern plant breeding methods, but in the general movement of many seeds the trend from a commodity to a speciality basis needs to be encouraged vigorously by agronomists. The problems of "how" this trend can best be encouraged challenge plant breeders and associated agronomists to greater efforts.

Such thoughts were expressed recently in a conversation with a seedsman. His comment was simply, "There's no demand for such seed; if so, we would service it." I wonder. Why, for instance, aren't there wider demands for red clovers and alfalfas of the highest known adaptations? Were we as agronomists to take more responsibility in seeing that these desirable strains really get a chance, would not the best of them come into sufficient prominence to be in active demand? Even the telephone and radio did not come into being as the result of demands! The odds are high against most new developments unless their acceptance and use are sponsored by some group.

The second example is really a specialized phase of the first. In the field of forage and pasture crops, there is at present tremendous plant

breeding activity. These intensive plant breeding attacks will result in superior strains, but many of these efforts will be nullified unless far more attention is directed both in research and extension toward the problems of multiplication, maintenance of identity, distribution, and utilization. With the advent of these new and superior strains, the production of seed of forage and pasture crops must be shifted from incidental farm enterprises to deliberate planned programs. The best thought in research and extension will be required to fit together the elements into sound, sensible programs of increase and distribution. Production and marketing costs will be increased for it will become necessary that identities of strains and lots be maintained through all stages of multiplication and distribution.

In what ways can prospective users of these improved strains be best brought to a realization of the value and economy of using them? How can they make certain the purchase of seed of the specific strain or blend desired? Because these problems of seed production and use will ignore state lines, the integrating process between research and extension will require coordination on regional or zone bases. It would be wise to initiate studies and preliminary plans of the functions research and extension are to play in this developing field. I believe that these problems with forage crops will be much more varied and far more difficult than those faced in the Corn Belt in recent years in the development and use of corn hybrids.

By way of summary, integration of research and extension in agronomy is stimulated by certain observances and practices. Above all, those going into extension in agronomy should be *as* well trained in the fundamentals of agronomy and contributing sciences as those going into research. To the extension worker the well-established principles of these sciences should be ever ready tools to be used in building projects and analyzing situations.

The interpretation of science challenges the younger agronomists, and the translation of the ideas and materials created by agronomic science into useful systems of soil and crop management offers opportunities for service fully as attractive as does the acquisition of new facts or the creation of new materials.

Integration will be facilitated if there is participation of each group in overlapping activities. The planes of demarcation should not be flat but rather interlocking. The research worker need not become an extension worker, but each will profit by familiarity with some of the problems and methods of the other. Integration is facilitated whenever extension agronomists assist in analyzing and classifying research problems that have been suggested from their activities or relationships. The extension agronomist moves toward the integrated objective when research agronomists suggest ideas and materials that are seemingly ready for extension. Cooperative discussion and planning of investigations and projects activate the integrating processes.

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THE CORRELATION OF THE EXTENSION AGRONOMY PROGRAM WITH THE RELATED PROGRAMS OF THE SOIL CONSERVATION SERVICE, THE FARM SECURITY ADMINISTRATION, AND THE AGRICULTURAL ADJUSTMENT ADMINISTRATION[1]

T. G. STEWART[2]

IT has been rather easy to correlate programs of the Farm Security Administration, A.A.A., and S.C.S. with the extension programs in Colorado for three reasons. First, we suspect that extension workers or former extension workers have had a great deal to do with writing the new programs. Extension interpretations, viewpoints, and relationships appear quite frequently.

Second, we find former extension workers in many of the administrative positions in S.C.S., A.A.A., and Farm Security. The first state coordinator of the S.C.S. was formerly an extension agronomist in Colorado and the present acting coordinator was formerly a county agent. The 1937 A.A.A., program for the Western Region was largely written by a former extension agronomist with state technical committees acting in an advisory capacity. The executive secretary for the A.A.A. in Colorado was a county agent for 21 years. The State Rehabilitation Supervisor for Farm Security and the Regional Director of Land Purchase in the Dust Bowl for the Bureau of Agricultural Economics were former Colorado county agents.

Third, under the able leadership of our Extension Director there has been in operation for more than a year an Agricultural Clearing Committee composed of the administrative heads of all federal and state agencies having an agricultural program in the state. Early meetings of this Clearing Committee were devoted to an explanation and discussion of the policies and programs of each agency. The function and program of each agency has been printed for the information of the membership. There are frequent changes and interpretations to be discussed, together with other topics provided by program committees at the regular meetings of the Clearing Committee.

It is not at all surprising to find that as men become acquainted they discover that the program of each agency is fully justified, that there is sufficient work to be done to keep all busy, and that it is possible to work together on a coordinated program pointing toward a planned agriculture for the state and an agricultural plan for each farm or ranch.

The Agricultural Conservation Program is a *device* to be used to the maximum extent by all agencies in securing the adoption of desirable extension agronomic practices. Certainly any extension agronomist should welcome the persuasive powers of the blue check to add to the persuasive powers of education in hastening the development

[1]Contribution from the Extension Service, Fort Collins, Colo. Also presented on the Extension Program at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication January 24, 1938.
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of the crops and soils program. The educational field in connection with the development of the A.C.P. remains within the extension service. The A.A.A. has created such a demand for information that we have had difficulty in supplying it. Our county agents have been so loaded with mechanics and details that they have not had time to devote to the intensive educational program when education was needed. We hope that this rough spot will soon be smoothed over.

We appreciate the special basic or research publications coming from Iowa on the Economics of Agricultural Adjustment. In Colorado we are attempting to meet the immediate demand of farmers and ranchmen for information on the practices and requirements of the A.C.P., Farm Security Administration, and S.C.S. program through a group of popular circulars, as follows:

Keep Your Farm Productive:

1. Rotate your Crops on Irrigated Land.
2. Rotate your Crops on Dryland.
3. By Controlling Noxious Weeds.
4. By Controlled Summer Fallow.
5. By Seeding Alfalfa and Clovers.
6. Plant a Permanent Irrigated Pasture

Save Your Soil:

7. By Terracing.
8. How to Run Contour and Grade Lines.
9. Establish Grass on Non-irrigated Land.
10. By Saving the Runoff.
11. Plant Shelterbelts and Windbreaks.

Improve Your Range:

12. Practice Proper Grazing.
13. By Rodent Control.
14. By Reseeding and the Use of Annual Pastures.

We look upon Farm Security as another *device* which can be used to put the extension agronomy program into effect on many farms. Land use studies and rural sociological problems mapped by Farm Security, together with Soil Conservation Service soil reconnaissance surveys, serve to point the way for action programs of all agencies. Farm Security rehabilitation supervisors encourage the purchase of pure seed of standard varieties. They are attempting to finance only an improved soil management program on the farms of their clients. In our greater problem area, the so-called Dust Bowl, there is a tendency to finance with Farm Security money clients only on economic units who are willing to follow a safer plan of farming. Again the persuasive powers of loans from Farm Security may be added to the persuasive powers of education.

The S.C.S. program is largely educational by demonstration, somewhat the same as the extension method of teaching. The Soil Conservation Service offers the persuasive powers of a great amount of service and some material aid to farmers on project or camp areas. The big job of soil conservation still lies outside of the project and camp areas. Is it not the sensible thing to do to combine the S.C.S. and extension programs and move soil conservation to all sections of the state and, if possible, to every farm or ranch in the state?

We have begun moving the soil conservation program into areas away from projects and camps through the cooperative farmer-demonstrator. The county agent picks the demonstrator, S.C.S. technicians map the farm, and the farmer, county agent, Soil Conservation specialist, and S.C.S. technicians plan the conservation program. The farmer carries out the 5-year conservation plan for his farm with the supervision of county agent and other technicians. This cooperative program has provided 74 farm demonstrations in Colorado at locations convenient to many farmers throughout the state. These cooperative farm demonstrations take advantage of the provisions of the A.A.A. and sometimes Farm Security and we believe have a tendency to shift the job of conservation back to the farmer.

Our Agricultural Clearing Committee recognized the need for a zoning law and some kind of a law which would protect a restoration or revegetation and conservation program.

The Clearing Committee, through its legislative committee, favored the passage of the Soil Erosion District law, patterned after the standard act which was favored in some 22 states, with slight modification. The Soil Erosion District law passed the Colorado Legislature without a dissenting vote. We see in this law another device effectively to correlate and coordinate the programs of all agencies into an action program which will become the program for the district.

The Soil Erosion District law will provide local organizations and adds the police powers, if needed, to the persuasive powers of education, A. C. P. payments, and Farm Security loans or grants in carrying out a more effective conservation program—an excellent opportunity, we believe, to expand the extension agronomy program.

Just now we are experimenting with county coordinating committees, patterned after the State Clearing Committee, in the hope that field workers may more effectively cooperate in carrying out action programs in the counties to avoid the appearance of duplication of effort.

The County Coordinating Committee is organized as follows:

County agent, chairman.

R. R. Supervisor of Farm Security Administration.

Representative of the S.C.S. wherever such individual is available.

All members of the county A.C.P. committee.

One farmer member of the Board of County Commissioners, to be designated by the Board of Commissioners.

Chairman of the County Planning Committee.

Representative of the Farm Credit Administration.

One member of the Board of District Supervisors of any soil erosion district which may be organized in the county.

Representative of the Land Utilization Division, Bureau of Agricultural Economics, such as Repurchase Project Manager.

If agencies other than these listed are to be included in these county coordinating committees, such additions will be subject to the approval of the State Agricultural Clearing Committee.

While we do not know how well it will work, we do believe that some such general plan of organization may be used to correlate the

programs in extension agronomy with the related programs of the S. C.S., the Farm Security Administration, and the Agricultural Adjustment Administration. In Colorado we rather like this slogan. "There is no limit to the amount of good which one can do if he does not care who gets the credit."

INHERITANCE IN A CROSS BETWEEN *AVENA SATIVA* AND *AVENA STERILIS LUDOVICIANA*[1]

G. K. MIDDLETON[2]

THIS is a study of the inheritance of kernel characters and linkage relations in a cross between *Avena sativa* var. Aurora and *A. sterilis Ludoviciana*, a wild form. Characters studied were basal articulation, color of lemma, dorsal and basal pubescence, and strength of awn. Of especial interest was the occurrence in certain families of plants of the *A. fatua* type.

REVIEW OF LITERATURE

BASAL ARTICULATION

Unit-factor differences for type of basal articulation have been found in most species crosses in oats, including crosses of *A. fatua* × *A. sativa* (19, 13)[3], *A. fatua* × *A. byzantina* (14, 12), *A. fatua* × *A. sterilis* (5), and *A. sterilis* × *A. sativa* (5). In a cross of *A. byzantina* var. Coast-black × *A. fatua*, Florell (5) found a two-factor difference, the segregation in F_2 giving 15 non-articulate to 1 articulate. When classified as to species types, the segregation was 12 *byzantina*: 3 *sterilis*: 1 *fatua*.

In a study of inheritance in *A. fatua*, Surface (19) found complete linkage between the wild-type base, or callus, strongly geniculate and twisted awns on both lower and upper kernels, pubescence on the rachilla segment of the second floret, and the ring of hairs around the callus. The inheritance of this "wild-oat complex" as a unit in a cross of *A. fatua* and *A. sativa* was also reported by Love and Craig (13) and by Florell (5). The latter found a complete linkage of these characters in each of seven interspecific crosses with the exception of *A. fatua* by *A. byzantina* var. Fulghum. In this cross slight crossing over occurred, which produced a few wild *sterilis* and also what appeared to be *sativa*-like plants. This led Florell to conclude that this character complex is controlled by two or more closely linked factors.

In addition to studies of inheritance in artificial crosses, a great deal of attention has been given by various workers to the occurrance of fatuoids, or false wild types, in fields of cultivated oats. Natural crossing, gene mutation, and chromosome aberration have each been proposed as the possible origin of these aberrant forms. In a recent paper, Aamodt, Johnston, and Manson (1) compared the segregation of artificial crosses of *A. fatua* and *A. sativa* with segregation of fatuoids found in fields of cultivated oats, and stated that, "Fatuoids, or false wild oats, identical morphologically and genetically with common fatuoids, appeared as normal Mendelian segregates from both natural and artificial crosses." They

[1]The data have been presented by the author in a thesis to the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy. The material for this study was furnished by Dr. H. H. Love, Department of Plant Breeding, Cornell University, Ithaca, N. Y., where the original cross was made and the first and part of the succeeding generations were grown. Received for publication December 6, 1937.

[2]Formerly graduate student, Cornell University, now Agronomist in Plant Breeding, North Carolina Agricultural Experiment Station, Raleigh, N. C.

[3]Figures in parenthesis refer to "Literature Cited," p. 207.

concluded that so far as the common type fatuoid is concerned, natural hybridization is the principal way in which they originate. Zade (21) and Tschermak (20) had earlier expressed the view that false wild types were the result of natural crosses. Huskins and Fryer (9), Huskins (10, 11), Jones (12), and Philip (17), on the other hand, from extensive genetic and cytological studies, favor the idea of chromosome aberration. Huskins (11) describes four types of fatuoids which differ in their chromosome number. He states, "In heterozygous fatuoids, which give different segregation ratios, different distinct cytological conditions have been found. The combined cytological and genetical evidence seems clearly to show that fatuoids arise from normal oats, neither by natural crossing between *A. sativa* and *A. fatua* nor by gene mutation, as previous authors have believed, but by chromosome aberration."

Coffman and Taylor (2, 3) report the spontaneous appearance of 0.2% fatuoids in lines of normal Fulghum oats that had been self-pollinated for four generations.

COLOR, PUBESCENCE, AND AWNS

Independent segregation of factors for black, grey, and yellow in a ratio of 12: 3: 1 was reported by Surface (19) and by Love and Craig (13). Aamodt, Johnson, and Manson (1) reported a similar segregation of factors for black, grey, and white. These were all crosses of *A. fatua* and *A. sativa*. In a cross of *A. byzantina* var. Burt by *A. sativa* var. Sixty Day, Fraser (6) obtained in F_2 approximately 48 red: 15 yellow: 1 white-kerneled plant. Odland (16) found a single factor difference between black and white in a cross of *A. sativa* var. Early Gothland and *A. sativa orientalis* var. Garton

Surface (19) found the factor for dorsal or lemma pubescence on the lower kernel closely, but not completely, linked with that for black, and basic to the development of pubescence on the upper kernel. When the basic gene was present, pubescence on the upper kernel segregated independently. Two genes for pubescence, one linked with and one independent of that for black color, were found by Love and Craig (13) and by Philp (17). Love and Craig found a relationship to exist between the yellow color of Sixty Day and the absence of awns and pubescence and the wild base. The yellow oats color inhibited awns and pubescence and oats with yellow kernels exhibited no wild type of base. Nilsson-Ehle (15) found an inhibitor to awning linked with yellow in a study of the inheritance of the weak awn in a cross between an awnless variety and one which had an average of 54% of awns. Love and Fraser (14) and Fraser (6) made a very detailed study of the inheritance of the weak awn in their cross of Sixty Day, an awnless variety, and Burt, a fully awned type. There was nearly complete dominance of the awnless condition in the first generation. The second generation gave awnless, partly awned, and fully awned plants in approximately a 1: 2: 1 ratio. A third generation test showed the fully awned condition to be the recessive. The data indicate that while Sixty Day carries an inhibitor to awning linked with the gene for yellow, no such factor is associated with the yellow gene carried by Burt. It was pointed out that the occurrence of awns in the awnless and partly-awned groups was apparently influenced somewhat by environment. Linkage was found between the Burt type of base, medium long basal hairs, and a fully awned condition. Short basal hairs or no basal hairs were found dominant over those which are medium long.

Philp (17) found the factors for white lemma (the double recessive) inhibited lemma pubescence. Aamodt, Johnson, and Manson (1) found no lemma pubescence on white-kerneled plants but found all black lemmas to carry pubescence,

and stated that it is obviously a case of linkage between genes for black and pubescence, or that the expression of pubescence is inhibited by the factor for white lemma color.

In crosses of Ruvia (*A. sterilis*) and three varieties of *A. sativa*, Cotner (4) obtained approximately 15 smooth: 1 pubescent plant, pubescence being brought in by Ruvia.

MATERIALS USED

The data presented here are from a cross between *A. sativa* var. Aurora and *A. sterilis Ludoviciana*. These two forms are referred to as the *sativa* and wild parents, respectively.

The kernel of the wild parent is brown or reddish black in color. Both kernels have strong geniculate, twisted awns, and both are dorsally pubescent, though that on the lower kernel is often the heavier. The base of the lower kernel is expanded into a sucker-like ring or callus which permits the grain to shatter easily. When the lower and upper kernels are separated the rachilla adheres to the upper, as distinct from the condition in *A. fatua* where it separates from the upper. From the callus around the base of the lower kernel, and also from the lower part of the rachilla of the upper, grows a thick ring of basal hairs. The length of these hairs is approximately $\frac{1}{16}$ inch, and is referred to as short.

The base of the other parent is that of the true *A. sativa*, and is rather compressed. Upon separation of the kernels the rachilla breaks free from the upper. The grain of this variety is yellow. This is a good yellow when grown in the greenhouse, but upon weathering in the field takes on a slight reddish cast. This variety is generally considered to be smooth as regards awns and pubescence, and no dorsal pubescence was ever found. An examination of the parental material as grown both at Ithaca, N. Y., and at Raleigh, N. C., revealed the presence of only an occasional hair, these being about $\frac{1}{8}$ inch in length. The material grown at Ithaca showed no awns, but of the plants grown at Raleigh four produced one very weak awn each and on one plant 40% of the spikelets bore awns.

METHODS OF STUDY

The parents and the first generation hybrids were grown in the greenhouse at Ithaca, N. Y. Subsequent generations were grown in the field, part at Ithaca, N. Y., and part at Raleigh, N. C. Two F_1 families, 437a1 and 437a2, were planted at Ithaca and gave a total of 503 F_2 plants. Lines from these two families were used for study in F_3 and later generations. In addition to these two lines, families 437a3, 437a4, and 437b1 were grown at Raleigh, N. C., and increased the total F_2 population to 868 plants.

A number of families were grown for F_3 but due to unfavorable weather conditions most of this material was lost. Twenty-five families were planted another year and in general produced good material for study. In these families as large numbers as possible were secured. In addition to these, a complete F_3 generation was grown from the F_2 material of family 437a2. This was done by planting single 4-foot rows from each F_2 plant. This same procedure was also used in checking all F_2 nonblacks in family 437a1, and for other questionable types of inheritance in F_2 and in certain F_3 families.

RESULTS

INHERITANCE OF BASAL ARTICULATION

The wild base is distinguished easily by the sucker-like mouth, while that of the *sativa* form is narrow and contracted. The F_1 ap-

peared like the *sativa* form but could be distinguished from it. In later generations the intermediates were separated from the *sativa* types by the breaking of the rachilla; when it broke easily from the upper kernel, the plant was classed as *sativa*, but when it would hang or break with difficulty, it was called intermediate. (See Fig. 1.)

The F_2 gave approximately 1 *sativa:* 2 intermediate: 1 wild, indicating a single gene difference for type of basal articulation. The observed numbers in these three classes were 231: 423: 214, respectively. Due to the difficulty in clearly separating the intermediate and true *sativa* plants in all cases, these two classes have been grouped together in Table 1.

TABLE 1.—*Showing the segregation as to type of basal articulation in F_2 in a cross of A. sativa var. Aurora × A. sterilis Ludoviciana.*

Basal articulation	Observed	Expected	D	P. E.	D/P. E.
Cultivated	654	651.0	3.0	8.60	0.35
Wild	214	217.0			

The breeding behavior in F_3 was in agreement with the results of F_2, 5 families breeding true for *sativa*, 12 segregating, and 5 breeding true for the wild-type base. A summary of the segregating families shows 287 *sativa;* 483 intermediate: 244 wild plants.

In one F_2 family, and again in certain F_4 families, a few *fatua*-like plants occurred. Because of certain association of characters, however, a discussion of these forms is left until later.

INHERITANCE OF COLOR OF KERNEL

In the description of the varieties used it was noted that the color of the *sativa* parent was yellow and that of the wild parent brown or reddish black, which is hereafter referred to as black.

The F_1 was black, while the F_2 segregated for black, red, and yellow in numbers approximating a 12:3:1 ratio. The red sorts were a very light shade of red and in case of weathering, or when a plant was slightly immature when harvested, the correct classification of the reds and yellows was difficult. Samples of seed from different red and yellow varieties were used as standards, but as the shades of color in these did not match the material being studied they were not satisfactory. Finally, standards were set up within one well-matured F_3 family, 437a2-64, by mounting typical seeds of each plant. This family was segregating for red and yellow only. It had previously been noted that in the F_2 material all wild non-blacks were red, and that the confusion arose in separating the red and yellow sorts in the cultivated classes. When the family mentioned above was mounted, it was found that all those in the wild group were red, those in the *sativa* group yellow, and those in the intermediate group intermediate not only for type of base but also for red and yellow color. When the well-matured families previously classified were rechecked on this basis, it was found that two agreed perfectly, while the others agreed with the exception of two or three plants each, and in these cases the

correct classification for basal articulation was as doubtful as was that for color. The F_2 data for the material grown at Ithaca, N. Y., are presented in Table 2.

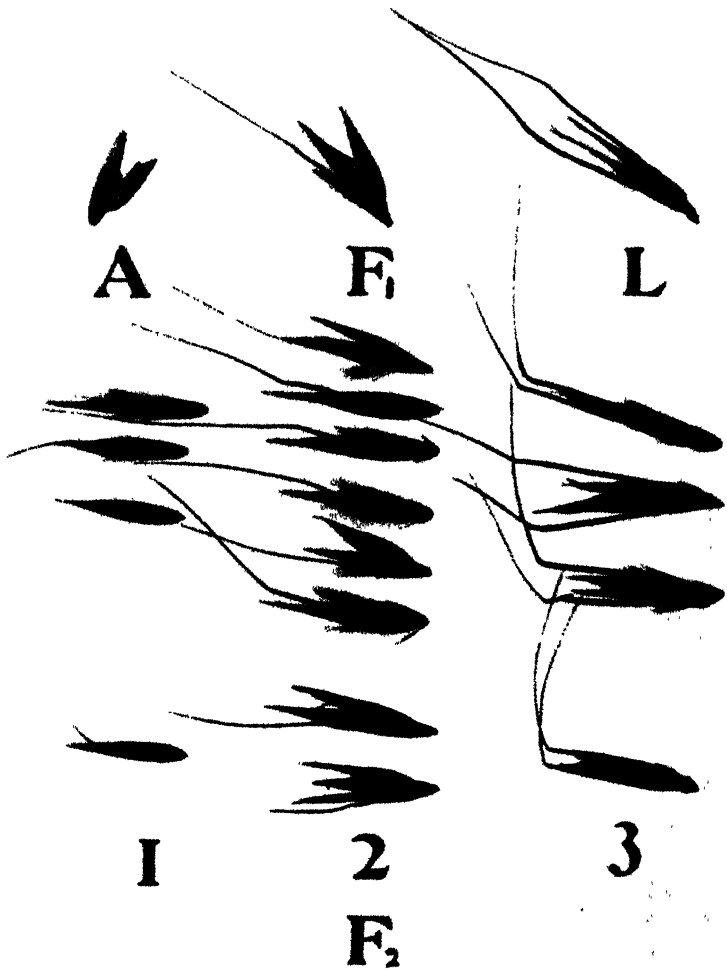

FIG. 1.—*Avena sativa* var. Aurora × *A. sterilis Ludoviciana*. A, Aurora; F_1, the hybrid; and L, *Ludoviciana*. Balance of figure shows representative F_2 segregates, grouped according to basal articulation and color as follows: 1, *sativa*; 2, intermediate; 3, wild *sterilis*. Ratios 1 : 2 : 1 for articulation and 3 : 1 for black and non-black. Complete color classification shows 12 black : 3 red : 1 yellow. There was very close linkage between the wild type base, strong geniculate, and twisted awns, complete ring of basal hairs around the callus and red color of kernel, the latter being hypostatic to black. There was also linkage between factors for black color and dorsal pubescence of kernel.

TABLE 2.—*Showing the segregation for color of kernel in certain F_2 families, 437a1 and 437a2, in a cross of A. sativa var. Aurora × A. sterilis Ludoviciana.*

Basal articulation	Color of kernel				
	Black	Red	Reddish-Yellow	Yellow	Total
Wild	85	22	—	—	107
Intermediate	206	—	58	—	264
Sativa	103	—	—	29	132
	394	80		29	503

For $n' = 2$, P is approximately .2.

The material grown at Raleigh, N. C., weathered somewhat and was classified simply as black and non-black. A summation of the entire F_2 data gives 677 black: 191 non-black, with a D/P. E. value of 3.02.

The interesting thing about the data in Table 2 is the linkage relation between genes for red color and the wild base. Whether there is a similar linkage between genes for yellow and the *sativa* base, or whether yellow is entirely independent and is simply hypostatic to red, can not be determined from the data.

The data from those F_3 families in which definite classification of the non-black plants could be made are in close agreement with that shown in Table 2, with a few exceptions.

In family 437a1–95 there occurred one break in the linkage between the genes for red color and the wild base. One plant which appeared as a true yellow in the intermediate group bred true for color in F_4, giving 21 cultivated: 5 wild, all of which were yellow.

There were a few cases in which red or yellow F_2 plants threw one or two black plants in F_3. Family 437 a2–51 produced two black plants and family 437a2–58 produced one, while all other plants in these families were non-black in color. Each of these black-kerneled types were planted and their behavior noted in F_4. One of these produced only dwarf plants which did not head; the second produced 6 black to 1 red-kerneled plant, and a number of dwarf plants; while the third produced 14 black: 4 red-kerneled plants.

In addition to these regular F_3 families, a single 4-foot row was planted from each non-black plant in certain F_2 families. Six out of 88 of these threw one black plant each, while otherwise they appeared to be normal for red or yellow. It is possible that natural crossing was responsible for some of these black-kerneled plants. Stanton and Coffman (18), Griffee and Hayes (8), and Garber and Quisenberry (7) have reported on the amount of natural crossing found in oats in Colorado, Minnesota, and West Virginia, respectively. This has been found to vary from only 1 natural cross in 7,742 plants in varieties of *A. sativa* at Morgantown, W. Va., to as high as 1.4% in one variety at University Farm, St. Paul, Minn. In breeding investigations with oats at the Cornell Agricultural Experiment Station, very little evidence of natural crossing has been observed.

In addition to this possibility of natural crossing, it is probably significant that in two of the three plants tested all or part of the progeny were dwarfs. This shows that at least part of these plants were abnormal and suggests the possibility of some chromosome aberration.

INHERITANCE OF PUBESCENCE AND AWNING

Dorsal pubescence.—Both kernels of the wild parent are covered with heavy dorsal hairs, though the upper kernel is usually less pubescent than the lower. The *sativa* parent is always smooth. The F_1 was black and pubescent on the lower kernel and had an occasional hair on the upper kernel.

In F_2 all black-kerneled plants showed dorsal pubescence on the lower kernel and all non-blacks were smooth, showing complete linkage between genes for black and pubescence. There were no exceptions to this in the third generation. While all black-kerneled plants were pubescent on the lower kernel, only part of them showed pubescence on the upper kernel in this generation. When this character is studied in connection with basal articulation, it appears that the latter is in some way modifying the appearance of pubescence on the upper kernel (Table 3).

TABLE 3.—*Showing the linkage of genes for dorsal pubescence and black color and the modification of the former in certain basal articulation groups in a cross of A. sativa var. Aurora × A. sterilis Ludoviciana.*

Wild			Intermediate			*Sativa*		
Black		Non-black	Black		Non-black	Black		Non-black
Number of Pubescent Kernels in the Spikelet								
2	1	0	2	1	0	2	1	0
85	—	22	178	28	57	33	70	30

It is to be observed in Table 3 that of 98 black-kerneled plants which showed pubescence on only one kernel, 70 were in the *sativa* group. Seventy-three of these, 28 from the intermediate group and 45 from the *sativa* group, were checked further in F_3. All of the intermediates and 33 of the 45 *sativa* plants tested produced some pubescence on the upper as well as on the lower kernel. The data are complete for family 437a2, and only 6 plants failed to produce some hairs on the upper kernel out of 25 so classified in the preceding generation.

The F_3 behavior of these one-kerneled-pubescent sorts indicates that they are probably all potentially pubescent on both kernels, but that environment or some modifying gene has affected their development.

Basal pubescence.—The wild parent has a ring of short heavy hairs growing out of the collar or callus which surrounds the base. The hairs are approximately $\frac{1}{16}$ inch long and are referred to as short. The *sativa* parent has a smooth base except for an occasional hair. In

examining the parental material only two such hairs were found, and these were 1/8 inch in length.

The F_1 was pubescent but not so much as was the wild parent, there being a small tuft of hairs on each side of the base. The length was slightly longer than in the wild parent, and approximated that found in the *sativa* parent, though in some cases it was slightly longer than 1/8 inch.

The complete F_2 data for the inheritance of this character are given in Table 4, in which it is noted that a new type of pubescence, designated long, has appeared. Those classified as long usually ranged from 3/16 to 1/4 inch in length, though in some cases there seemed to be no sharp line of demarkation between this and the intermediate length, one blending into the other. The intermediate and short classes are grouped together in the table.

TABLE 4.—*Showing the inheritance of basal pubescence in F_2 in a cross of A. sativa var. Aurora × A. sterilis Ludoviciana.*

Basal articulation	Length of basal hairs		
	Short	Long	None
Wild	150	64	–
Intermediate	302	124	2
Sativa	164	15	47
Total	616	203	49

The summary at the bottom of Table 4 indicates a 3:1 relationship between short and long, but with a non-pubescent group in addition. When this material was first classified, a much larger number was found in this group, but these were checked again, using a lens and examining 15 to 20 kernels before they were finally listed as non-pubescent. Of these, 35 were in two families. All of these were grown for F_3 and 32 of them gave some basal hairs in this generation, 23 being short and 9 long. It appears, then, that all probably carry a gene for pubescence and that they might be grouped simply for length. As seen in Table 5, omitting the three which showed no pubescence, a very close agreement for a 3:1 ratio is to be observed, the D/P. E.

TABLE 5.—*Showing the inheritance of basal pubescence in certain F_2 families, 437a1 and 437a2, of a cross between A. sativa var. Aurora and A. sterilis Ludoviciana, the data being arranged in accordance with their behavior in F_3*

Basal articulation	Length of basal hairs		
	Short	Long	None
Wild	76	31	–
Intermediate	186	77	–
Sativa	118	12	3
Total	380	120	3

value being .77. The other F_2 families were grown at Raleigh, N. C., and gave data similar to these, but the non-pubescent plants were not checked in F_3.

From an examination of the data in either Table 4 or Table 5, it appears that there is either a linkage relation or a modifying gene disturbing the normal segregation of short and long hairs in the wild and cultivated classes. It is hardly a case of linkage, however, as the wild parent has short basal hairs while from the data it would be expected that the reverse were true.

Within both the wild and intermediate groups there is a fair 3:1 ratio between short and long pubescence. The D/P. E. values for these two classes, from the data in Table 5, are 1.43 and 2.37, respectively. In the *sativa* class, however, the number of plants with long pubescence is greatly reduced. If χ^2 is calculated on a basis of six classes, omitting the three non-pubescent plants, a value for P less than .0002 is obtained.

It is concluded from the F_2 and subsequent behavior of this character that there is a single-gene difference between long and short pubescence; that long pubescence is brought in by the *sativa* parent, but that in the parent and in the *sativa* groups in subsequent generations its appearance is modified by another gene associated with the *sativa* base.

STRENGTH OF AWN

The wild parent has two strong geniculate, twisted awns with a black basal portion, while the cultivated form is awnless except for an occasional weak awn.

The F_1 was intermediate, producing one awn on all lower kernels but never on the upper; and that produced ranged from one that was geniculate and twisted to one that showed no twist and very little color at the base.

In F_2 (Table 6), all wild plants bore two strong awns like the parent, while the cultivated groups exhibited a complete range from one strong awn to no awns. This was true in both the intermediate and *sativa* classes, but with the weak and awnless types predominating in the *sativa* class.

TABLE 6.—*Showing the inheritance of strength of awn in F_2 in a cross of A. sativa var. Aurora × A. sterilis Ludoviciana.*

Basal articulation	Number and strength of awns				
	2 strong	1 strong	1 intermediate	1 weak	None
Wild	214	—	—	—	—
Intermediate	—	209	147	69	3
Sativa	—	24	50	127	24
Total	214	233	197	196	27

As there were no sharp distinctions that could be drawn between the classes, it was hardly to be expected that definite ratios could be

obtained. It was noticed in the F_3 breeding behavior of plants from these groups, that plants with one strong awn, would usually produce a complete range from strong to weak, that those of intermediate strength would tend to throw intermediates and weaks, and that the weak-awned plants tended to breed true or to throw a few plants with intermediate type of awn. This general behavior would indicate that possibly multiple genes were concerned if it were not for the fact that the parental types occurred in such large numbers in F_2.

Twenty-five of the awnless plants were tested in F_3 and all produced some weak awns. This shows that all were potentially awned though for some reason they had appeared as awnless plants in F_2. Having a complete range from strong-awned to awnless plants indicates that environment influences the development of this character. In addition to environment, however, it also seems possible that some genetical modifier may influence the strength of awns and that this modifier is associated with the gene which determines the *sativa* type of base.

This relationship is further emphasized in the following study on percentage of awning (Table 7). These data were obtained by taking a single panicle from each plant in certain families and counting the number of awned and awnless spikelets. The strong-awned plants were usually 100% awned, thus giving a much higher number of fully awned plants in the intermediate group.

TABLE 7.—*Showing the relation of basal articulation to percentage of awns in families 437a3, 437a4, and 437b1 in a cross of A sativa var. Aurora × A. sterilis Ludoviciana.*

Basal articulation	Percentage of awned spikelets						
	0	1-20	21-40	41-60	61-80	81-99	100
Wild	—	—	—	—	—	—	107
Intermediate	1	1	1	1	2	10	148
Sativa	2	3	3	6	16	23	40

The F_3 data in general support those of the preceding generation.

MODIFYING FACTOR

The data presented indicate that there is a factor, or factors, associated with the *sativa* base which inhibits or modifies the full expression of genes for awns and basal pubescence on the lower kernel and dorsal pubescence on the upper kernel. If the data on strength of awn and length of basal hairs are studied together, there is some evidence that both characters are modified by the same gene.

It was mentioned previously that in the *sativa* group of families 437a1 and 437a2 there were 35 plants classified as having no basal hairs. Twenty-five of these occurred in the group of weak awns to awnless, as given in Table 8. It is to be noted further that while only 3 plants in the *sativa* group were classified as having long basal hairs in F_2, 12 were so classified when the F_3 tests were completed. Of the nine plants with weak awns and long basal hairs found in F_3, seven

were from the weak and awnless groups and the other two from plants that had a very slight twist in the awn.

TABLE 8.—*Showing the relation of basal articulation to strength of awn and to length of basal hairs in families 437a1 and 437a2 of a cross between A. sativa var. Aurora and A. sterilis Ludoviciana.*

Basal articulation	Strength of awn and length of basal hairs								
	Strong			Weak			Awnless		
	Short	Long	None	Short	Long	None	Short	Long	None
				F_2 Data					
Wild	76	31	—	—	—	—	—	—	—
Intermediate	146	63	1	35	14	1	3	—	—
Sativa	47	1	10	36	2	14	11	—	11
				F_3 Data					
Wild	76	31	—	—	—	—	—	—	—
Intermediate	148	63	—	38	14	—	—	—	—
Sativa	55	3	—	62	9	3	—	—	—

In addition to a modifying gene associated with the *sativa* base, it is possible environment played a part in the appearance of these characters, as much of the F_3 testing of the awnless and non-pubescent plants was conducted at Raleigh, N. C., while the F_2 of the same families had been grown at Ithaca, N. Y. While it might seem that environment would affect their appearance and development in the wild, intermediate, and *sativa* types in much the same way, actually most of the modification seemed to be in the *sativa* group.

There is a morphological difference in the parental types which should be taken into consideration in the study of basal pubescence and that is suitable tissue from which the hairs can be produced. It was mentioned in the description of the base that in the wild parent there is a collar or callus surrounding it, and it is from this callus that a heavy band of basal hairs is produced. In the intermediate plants, the callus largely disappears, though the base is not contracted so much as in the *sativa* parent. The intermediates have a limited amount of pubescence, while in the *sativa* group it appears as only a trace or not at all. Possibly the difference in abundance of dorsal hairs on the lower and upper kernels may be explained in the same manner. The flowering glumes of the wild plants are coarse and ribbed. On intermediate and *sativa* plants this condition is found on the lower kernel but with the upper kernel almost smooth, especially in the *sativa* group.

Assuming that the basic genes are present, it seems possible that the amount of dorsal and basal hairs may be correlated with the abundance of suitable tissue for their development. A purely genetical gene or genes are, however, probably responsible for any modification of length of basal hairs which may take place, and the same genes possibly affect strength of awn. Such genes, together with environ-

ment, produce plants in the *sativa*-group which usually have very weak or no awns and only traces of short hairs or no basal pubescence.

OCCURRENCE OF *A. fatua* AND OTHER IRREGULAR TYPES

In the F_2 of family 437 a4, as mentioned earlier, a few *fatua*-like plants appeared, the complete segregation giving 146 cultivated: 63 wild *sterilis:* 4 *fatua*. The kernels of these four plants were black and dorsally pubescent and the spikelets bore two strong awns. They seemed to differ from the *sterilis* group only in articulation and size of kernel, the *fatua* forms being much more slender than the *sterilis*. The following year each of the four *fatua* plants bred true, but of 20 *sterilis* plants taken from this family no *fatua* segregates were found. If there had been normal segregation for *sterilis* and *fatua* in the wild group, some of the next generation families would probably have segregated 15 *sterilis:* 1 *fatua*, and others 3 *sterilis:* 1 *fatua*. Since no such segregation was observed, and as similar forms had not been found in any of the other four F_2 families, it was thought possible that these four plants were due to mechanical mixture.

In family 437a1 however, plant 116 was somewhat different from any other plant and among its progeny *fatua* segregates did occur. This plant had glabrous lemmas but was darker red in color than any other plant so classified. If it had been pubescent it might possibly have been grouped with the blacks. In F_3 an almost complete range of colors, from black to yellow, was found, including a number of reddish-grey and three pure grey-kerneled plants. Twenty-three plants, representing the various color shades, were chosen and planted to observe their behavior in F_4. A tabulation of the results secured shows that the black sorts produced only black, red, and yellow, while the red and reddish-grey plants occasionally threw grey. One of the grey plants segregated in F_4 for grey and yellow, while the other two gave a range from reddish-grey to yellow.

In three of these F_4 families *fatua* segregates were found. In family 437a1–116–62, which was intermediate in F_3, there was a segregation of 27 cultivated: 10 *fatua*, and in each of the other two families, 437a1–116–11 and 437a1–116–57, the segregation was 18 wild *sterilis:* 4 *fatua*. These *fatua* plants all had two strong geniculate awns, were dorsally pubescent, and had heavy basal pubescence, but were grey in color instead of black.

Fifteen plants were taken from family 437a1–116–62 and planted. Of this number 2 bred true for *sativa*, 9 segregated, and 4 bred true for *fatua*. A total of the segregating families shows 176 cultivated to 47 *fatua*. From the other two families very nearly a complete F_5, was grown. Of 40 F_5 families, 13 bred true for *sterilis*, 19 segregated, and 8 bred true for *fatua*, with slight irregularities in four of these. A summary of the segregating families gives 158 *sterilis* to 48 *fatua*. In the first case we have a fairly close 3:1 ratio for *sativa* and *fatua* and in the latter for *sterilis* and *fatua*.

A study of the *fatua* forms in these three families, as given in Table 9, shows a close linkage between the factors for *fatua*-type articulation and dorsal pubescence. All 18 *fatua* plants had heavy pubescence on

both kernels, while in the non-*fatua* groups a few plants produced a trace of pubescence, and this usually on the lower kernel only. The breeding behavior in F_5 was in agreement, all *fatua* plants being pubescent and the non-*fatua* plants having only a trace to no pubescence.

TABLE 9.—*Showing an apparent linkage relationship between factors for A. fatua type of articulation and dorsal pubescence in certain F_4 families in a cross of A. sativa var. Aurora and A. sterilis Ludoviciana.*

Family	Non-*fatua*		*Fatua*	
	Non-pubescent	Pubescent	Non-pubescent	Pubescent
11	15	3	0	4
57	15	3	0	4
62.	22	5	0	10
Total	52	11	0	18

In a review of the literature no reference was found to a linkage of these factors. In *fatua* forms, pubescence has usually been found linked with black color and this independent from basal articulation.

Each of the *fatua* plants found in F_4 also had grey-colored lemmas, while in the non-*fatua* group the color varied from reddish-grey to yellow. In this connection it should be mentioned that seeds from the parent plants of these three families were planted because they carried factors for grey color. If there was any linkage between the factors for grey color and *fatua* articulation, it was very weak. Three reddish-grey and one pure grey-kerneled F_3 plant failed to produce any *fatua* plants in F_4. Further, there seems to be independent segregation of factors for grey color and pubescence in the non-*fatua* groups of these three families and in other grey-colored families.

Unfortunately, the F_5 material did not develop good colors, and it was impossible to classify them correctly. The colors varied from reddish-grey to yellow.

The breeding behavior of these forms indicates that they originated through some chromosome aberration rather than natural crossing. The latter could not have accounted for the four *fatua* plants which occurred in the F_2 of family 437a4 as such a cross would necessarily have been between the *sativa* parent and an *A. fatua* plant and would have been expected to produce 3 cultivated: 1 *fatua* plant in F_2.

In the case of family 437a1, a cross between a single flower of the F_1 and an *A. fatua* plant, carrying factors for grey and pubescence, might have occurred. In this case, however, we would have expected a segregation of *sativa* and *fatua* or *sterilis* and *fatua* types in F_3, but *fatua* forms were not found until F_4.

In F_5, the behavior in most cases agreed with that expected, but in four families there were irregularities which would not be expected in normal segregating families. These four all appeared to be true *fatua* types in F_4, which was the recessive. In family 437a1–116–11, plant 7 gave 11 *fatua*: 2 *sterilis* and plant 22 produced 15 *fatua*: 1

sterilis. In family 437a1–116–57, plant 12 gave 4 *fatua:* 1 *sativa:* 1 *sterilis;* and in family 437a1–116–62, plant 7 produced 8 *fatua:* 1 *sativa*.

The series of irregular types of breeding behavior observed in this family, beginning with an off-colored, glabrous plant in F_2, the appearance of grey color in F_3, of *fatua*-type articulation linked with pubescence in F_4, and finally with the segregation of dominant types, *sativa* and *sterilis*, from *fatua* forms in F_5, would seem to be good evidence of chromosome aberration rather than natural crossing.

SUMMARY

Studies on the inheritance of certain kernel characters and linkage relations in a cross between *A. sativa* var. Aurora and *A. sterilis Ludoviciana* have been reported in this paper.

1. The cultivated type of basal articulation is dominant to the wild, with the intermediate forms usually distinguishable giving a 1:2:1 ratio.

2. The kernels of the wild forms are brown or reddish black and those of the cultivated are yellow. In F_1 these were black, while in F_2 there was a segregation for black, red, and yellow in numbers approximating a 12:3:1 ratio, with the gene for red linked with that for wild-type articulation. No yellow-kerneled plants were found with the wild-type base in a total F_2 population of 868, but in F_3 1 plant with intermediate-type articulation was yellow and bred true for this color in F_4.

3. Genes for dorsal pubescence and black color showed complete linkage in F_2 and F_3. These dorsal hairs appear in abundance on both kernels of wild, black-kerneled plants. In the cultivated groups, and especially in the true *sativa* group, dorsal pubescence is fairly abundant on the lower kernel but appears as a trace to none on the upper.

4. The wild parent has a heavy ring of short hairs surrounding the base of the lower kernel. These are produced on the collar or callus which surrounds the base. The cultivated parent has a smooth base except for an occasional hair, intermediate in length. The F_1 produced a tuft of hair on each side of the base, intermediate in length. In F_2 a new type of basal hairs, designated long, appeared. The intermediate forms were grouped with those with short pubescence, giving a ratio approximating 3 short: 1 long. This ratio held within either the wild or intermediate group, but in the *sativa* group very few plants produced long basal hairs. It is assumed that the gene for long pubescence was brought in by the cultivated parent, but in the parental material and in the *sativa* groups its appearance is inhibited or modified by an inhibitor associated with the gene which determines the *sativa* type of base.

5. The wild parent has two strong awns and the cultivated is smooth except for an occasional weak awn on the lower kernel. The F_1 produced one awn, varying in strength from twisted and geniculate to weak. In later generations the wild plants always bore two strong awns like the parent, showing linkage of these two factors. In the

cultivated groups only one awn was produced and showed a complete range of types, from strong, twisted, and geniculate, to weak or awnless. The data indicate that the same inhibitor which affects basal pubescence also modifies awns. Possibly environment may also have affected the development of this character.

6. A summary of all these studies shows a very close linkage relationship between genes for the wild *sterilis* base, red color of kernel, and two strong awns. In addition, heavy basal pubescence is also associated with the wild type of base and has been explained on the fact that the wild oats have a callus from which the hairs are produced. This is absent in the *sativa* parent. There is no evidence of linkage of genetic factors which determine length of basal pubescence and basal articulation.

7. One F_2 and three F_3 families produced a few *fatua*-like plants which apparently originated through some chromosome aberration.

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THE RELATION BETWEEN SINGLE AND DOUBLE CROSS YIELDS IN CORN[1]

D. C. ANDERSON[2]

WHEN four inbred lines have been selected to be used in a double cross, it is necessary to know which two single crosses, out of the possible six, should be used as parents to make the most productive double cross. Jenkins[3] presented data on four methods of estimating the yield of double crosses. These methods in brief consisted of (a) predicting the yield of the double cross on the basis of the average yield of the possible six crosses of the four inbred lines used in making the double cross; (b) predicting the yield on the basis of the average yield of the four single crosses not used in making the double cross; (c) prediction based on the average yield of the four inbred lines in all possible combinations with 10 other inbreds and these four averages averaged; (d) prediction based on the average yields of four inbred lines in top crosses.

The actual yield of 42 double crosses was correlated with the predicted, based on each of the four methods. Correlation coefficients calculated for actual yields related to predicted yields by methods A, B, C and D were 0.75, 0.76, 0.73, and 0.61, respectively, with a significant value represented by 0.39. Jenkins concludes that method D, while not as reliable, may be used fairly satisfactorily.

Doxtator and Johnson[4] emphasized the importance of predicting the best method of combining four lines in single and double crosses, especially in those cases where the single crosses differed widely in yields, and showed that method B of Jenkins could be used reliably in such cases. The top-cross method is now being used widely to select inbred lines on the basis of their combining ability. After making first crosses between these lines, one may then predict which combinations of each group of four lines can be used advantageously in making the single and double crosses for commercial use.

The present paper gives further evidence regarding the prediction of double cross yields from the yields of single crosses using method B as outlined by Jenkins. All possible 10 crosses have been studied between five inbred lines and the yields of the single crosses have been used to predict the best possible double cross from each group of four inbred lines.

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[4]DOXTATOR, C. W., and JOHNSON, I. J. Prediction of double cross yields in corn. Jour. Amer. Soc. Agron., 28:460-462. 1936.

MATERIAL AND METHODS

The data reported in this paper were obtained in 1937 at the University Southeast Experiment Station, Waseca, Minn. The 10 single crosses made from five inbred lines and the 15 double crosses made from these 10 single crosses were used in this study. The five inbred lines used in making these crosses were 23 and 24, two late inbreds from Reid's Yellow Dent, and 26, 27, and 28, three inbreds of medium maturity from Golden Glow. All of these lines have been inbred for at least 10 years. The 10 single crosses and three check strains were grown in randomized blocks. Four replications were made, each plat consisting of a single row 18 hills long. Only three-stalk hills surrounded by corn were harvested and the yields calculated on a perfect stand basis. Five replications of the 15 double crosses and the three check strains were grown in another randomized block trial in the same field. Single-row plats 18 hills long were used. In two replications, five seeds were planted per hill and later thinned to three plants each and only three-stalk hills surrounded by corn were harvested. In the other three replications three seeds were planted per hill and the entire row was harvested, disregarding stand. The interaction between the two tests was computed and found to be non-significant so the five replications were averaged together.

Significant differences were computed in bushels for each of the two trials and are given in the tables. These are based on differences of two times the standard error of a difference.

EXPERIMENTAL RESULTS

Yields of the 10 possible single crosses between the five lines are given in Table 1. The differences in yielding ability are highly significant. It would be expected then that there would be a significant difference in the yields of the double crosses.

TABLE 1.—*Yield of single crosses*

Cross	Bushels per acre	Cross	Bushels per acre
(23×24)	41.7	(24×27)	72.1
(23×26)	62.6	(24×28)	69.3
(23×27)	70.8	(26×27)	64.2
(23×28)	64.4	(26×28)	60.4
(24×26)	65.6	(27×28)	59.6

Difference required for significance 6.84.

Table 2 gives the actual and predicted yields for each of the 15 double crosses. The three different double crosses that can be made from four inbred lines are grouped together in the table. The predicted yield of the double cross was obtained by averaging the four single crosses not used as parents. For example, the predicted yield of the double cross (23x24) (26x27) would be the average of the four single crosses (23x26), (23x27), (24x26), and (24x27) which is 67.8 bushels. This is theoretically the highest yielding double cross that can be made with these four inbred lines. Actually it was the highest, yielding 68.8 bushels per acre as compared to 62.4 bushels for (23x26) (24x27) and 62.0 bushels for (23x27) (24x26). These yields agreed very closely to the ones arrived at by prediction.

The predicted yield of (23x24) (26x28) and the actual yield are about the same, being respectively 65.0 and 65.5 bushels, while the other two combinations of 23, 24, 26, and 28 gave significantly lower predicted and actual yields.

TABLE 2.—*Actual and predicted yield of double crosses.*

Cross	Bushels per acre		Cross	Bushels per acre	
	Actual	Predicted		Actual	Predicted
Lines combined, 23, 24, 26, 27			Lines combined, 23, 26, 27, 28		
(23×24) (26×27)	68.8	67.8	(23×26) (27×28)	68.2	65.0
(23×26) (24×27)	62.4	60.6	(23×27) (26×28)	65.0	62.7
(23×27) (24×26)	62.0	60.2	(23×28) (26×27)	65.7	63.4
Lines combined, 23, 24, 26, 28			Lines combined, 24, 26, 27, 28		
(23×24) (26×28)	65.0	65.5	(24×26) (27×28)	70.2	66.5
(23×26) (24×28)	59.8	58.0	(24×27) (26×28)	62.0	64.7
(23×28) (24×26)	56.0	58.5	(24×28) (26×27)	62.7	64.4
Lines combined, 23, 24, 27, 28					
(23×24) (27×28)	71.1	69.2			
(23×27) (24×28)	58.1	59.4			
(23×28) (24×27)	58.0	60.4			

Difference required for significance, actual, 5.26
Difference required for significance, predicted, 3.41

In a similar way it may be seen that the combination of (23x24) (27x28) gave much higher predicted and actual yields than any other combinations of these four lines. Differences were not so great in the predicted yields of 23, 26, 27, and 28 in combination and the actual yields were not widely different. The predicted yields for 24, 26, 27, and 28 in combination were not significantly different, although in this case one combination of the four lines yielded significantly better than the other two.

The coefficient of correlation computed between the actual and the predicted yield of the 15 double crosses, $r = .90$, is highly significant.

SUMMARY

The actual yield of 15 double crosses and the predicted yield as obtained by averaging the yield of the four single crosses not used as parents were compared. The results show a close agreement between the predicted and the actual yield of the double crosses.

If top crosses are used to pick out inbred lines for testing in double cross combinations, it is apparent from these results that it is highly desirable to study all possible single crosses between each of four lines in order to determine how they should be combined.

ROW SPACING AND RATE OF SEEDING FOR RICE NURSERY PLATS[1]

N. E. JODON and H. M. BEACHELL[2]

IN America the same technic is followed in conducting yield tests with rice as with other small grains, except that the land is submerged during the most of the growing season. A departure from the conventional three-row nursery plat with the rows 12 inches apart and only the center row harvested for yield would appear to have the following possible advantages: (a) Less space between rows would more nearly approximate the usual farm practice and give better control of weeds and grasses; (b) in 36-inch or 40-inch plats with rows spaced 6, 8, or 10 inches apart, four, three, or two inside rows could be harvested and the larger proportion of the plat harvested should tend to reduce variability; (c) a better distribution of plants over the area sown in rows more closely spaced might also tend to increase yields; and (d) additional seed would be available for more extensive tests.

Possible disadvantages in spacing rows less than 12 inches apart are (a) difficulty in seeding on rough seedbeds; (b) difficulty in weeding and roguing on submerged land; and (c) increased plant competition for light and nutrients.

Similar experiments herein reported were conducted in 1936 at the Rice Experiment Station, Crowley, Louisiana, and the Texas Agricultural Substation No. 4, Beaumont, Texas, to study the effect of closer spacing between rows on yield and variability.

PROCEDURE AND EXPERIMENTAL CONDITIONS

The split strip experimental design was used to permit a study of the distribution of the seed into rows 6, 8, 10, and 12 inches apart for each rate of seeding. Plats for the 6-inch spacing were six rows wide, those for the 8-inch spacing were five rows wide, those for the 10-inch spacing were four rows wide, and those for the 12-inch spacing were the usual three rows wide.

The experiment at each location comprised four blocks. Each block consisted of 16 plats involving the 16 possible combinations of four varieties with four rates of seeding. Each plat was subdivided into four sub-plats for the four-row spacings. The varieties used were Caloro (medium to early), Fortuna (medium maturity), Blue Rose (late), and Rexoro (very late). The rates of seeding were 60, 80, 100, and 120 pounds per acre. At Crowley the four blocks were arranged in a square, but at Beaumont they were in a single series. Limited transplanting was necessary to obtain uniform stands in certain plats at Crowley, but at Beaumont the stands were as nearly perfect as could be expected.

The plats at Crowley were sown May 4 and 5, the seedlings were fully emerged about May 24, and the land was submerged June 8. Water was maintained on the

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[2]Assistant Agronomists. The authors wish to express their appreciation to Dr. F. R. Immer of the University of Minnesota for aid in organizing the experiment and in the preparation of this paper.

field until Rexoro ripened. At Beaumont the plats were sown on April 20 and 21 and were irrigated and immediately drained on April 25 and again on May 6. The land was submerged June 9, resubmerged on June 22 after the soil had dried, and a normal depth of water was maintained thereafter throughout the growing season. All varieties, except Rexoro, were harvested before draining the water from the plats.

In the area used for the experiment at Crowley, three levees running in the same direction as the plats had been leveled more than a year before the experiment was conducted. Growth was poorest on the bases of the old levees and best on the sides. This land (Crowley silt loam) had been in rice and soybeans alternately from 1916 to 1930, and rice and fallow in alternate years beginning 1930. No fertilizer had ever been applied.

The area used for the experiment at Beaumont was Crowley clay, dark phase, and was of uniform topography. The land was cropped to rice in 1925 and 1926, to soybeans in 1927, to cotton in 1928, and was summer fallowed in 1929. During the period of 1930–1933, inclusive, the land was planted to corn in the early spring and followed by a leguminous crop in the fall. The corn was fertilized each season, but no record is available as to the amount or composition of the fertilizer applied. The area was cropped uniformly to rice in 1934 and summer fallowed in 1935.

The mean annual rainfall at Crowley is 55.97 inches and in 1936 the total was 41.54 inches. The mean for the growing season, April to September, inclusive, is 28.51 inches, and the total in 1936 was 22.82 inches. The corresponding rainfall at Beaumont was 53.71 and 48.48 and 28.06 and 32.08 inches, respectively. The seasonal weather conditions at the two stations usually are not greatly different because the stations are only about 120 miles apart with about 10 miles difference in latitude and both are within 50 miles of the Gulf of Mexico.

RESULTS

The yield data in bushels per acre by individual sub-plats, together with the means of each of the 64 combinations of varieties with rates and spacings, are given in Table 1. The mean yield of the rice in the experiment at Crowley was 32.8 bushels per acre and at Beaumont 54.5 bushels. The F values (4)[3] from the analysis of variance (Table 2) show that the differences among the varietal yields were highly significant at each station. Rexoro, Fortuna, and Caloro produced considerably higher mean yields than did Blue Rose (Table 3). The mean yield of Blue Rose was 6.1 to 9.8 bushels less than that of the other varieties at Crowley and 13.5 to 14.9 bushels less at Beaumont.

The small differences in mean yields from the different rates of seeding were not significant. At Crowley there was a maximum difference of 3.7 bushels between plats with rows spaced 6 inches apart and those with wider spacings. There was a consistent increase in yield as the space between the rows was reduced from 12 to 6 inches. The analysis of variance indicates that the odds are considerably higher than 99:1 that the yield differences from the variations in spacing at Crowley were significant. At Beaumont, however, the differences were very small and not significant.

The interactions, varieties x rates, spacings x varieties, spacings x rates, and spacings x varieties x rates were not significant. The mean

[3]Figures in parenthesis refer to "Literature Cited," p. 219.

TABLE 1.—*Plat yields in bushels per acre from varieties, rates, and spacings.*

Rate of seeding, lbs.	Row spacing, in.	Acre yield in bushels									
		Crowley, La., blocks					Beaumont, Texas., blocks				
		1	2	3	4	Mean	1	2	3	4	Mean
						Caloro					
60	6	34.0	28.5	29.9	27.6	30.0	54.6	56.0	53.4	57.2	55.3
	8	26.9	29.5	28.1	39.6	31.0	56.5	59.0	60.3	62.5	59.6
	10	33.5	32.2	29.1	29.1	31.0	55.4	69.8	60.0	61.4	61.7
	12	21.3	26.9	29.3	29.9	26.9	46.4	59.4	56.6	60.8	55.8
80	6	28.4	31.5	31.5	39.3	32.7	41.3	53.4	59.2	52.5	51.6
	8	30.0	30.1	34.5	32.8	31.9	46.3	51.4	60.0	73.0	57.7
	10	27.5	31.4	34.9	37.0	32.7	52.9	59.1	64.9	61.0	59.5
	12	28.3	30.4	26.7	36.5	30.5	57.5	65.9	59.4	74.0	64.2
100	6	31.3	36.0	36.5	46.4	37.6	46.4	55.4	55.2	55.9	53.2
	8	28.1	42.1	35.3	37.7	35.8	52.6	59.2	63 9	56.0	57.9
	10	25.4	32.2	33.1	40.2	32.7	64.6	57.0	59.0	57.9	59.6
	12	37.1	27.7	30.1	32.0	31.7	58.3	66.6	55.1	52.2	58.1
120	6	40.3	42.5	33.1	39.7	38.9	74.2	55.8	55.4	64.4	62.5
	8	31.5	42.9	34.1	33.6	35.5	67.8	61.6	61.4	59.2	62.5
	10	34.4	38.4	37.6	34.7	36.3	70.1	61.9	55.9	49 1	59.3
	12	27.5	33.3	31.5	38.1	32.6	69.2	57.8	64.2	55.1	61.1
						Fortuna					
60	6	24.8	34.4	38.3	39.2	34.2	62.4	58.2	63.0	64.7	62.1
	8	32.7	24.7	37.3	43.2	34.5	36.3	61.5	56.8	51.1	51.4
	10	25.8	26.6	40.3	34.7	31.9	54.9	49.4	54.5	51.3	52.5
	12	29.6	26.4	29.9	36.8	30.7	48.4	57.4	54.4	52.3	53.1
80	6	36.4	42.4	31.9	41.3	38.0	47.3	61.8	56.2	61.4	56.7
	8	35.2	34.8	30.8	27.1	32.0	55.0	54.5	64.0	54.4	57.0
	10	28.5	32.8	30.7	32.7	31.2	53.3	56.2	61.4	57.9	57.2
	12	25.3	42.9	23.7	29.9	30.5	59.1	60.3	53.1	59.5	58.0
100	6	37.2	28.1	46.8	35.2	36.8	55.0	55.5	61.4	63.0	58.7
	8	27.1	38.4	34.5	42.0	35.5	50.2	57.6	59.4	57.4	56.2
	10	39.4	37.5	41.6	35.7	38.6	60.7	59.7	58.5	63.4	60.6
	12	44.5	31.7	36.3	34.4	36.7	62.0	56.0	62.6	48.8	57.4
120	6	27.3	45.3	43.7	41.1	39.4	64.8	61.8	59.6	70.0	64.1
	8	31.5	31.1	45.2	39.2	36.8	48.3	60.0	56.8	67.0	58.0
	10	25.6	29.8	47.5	37.0	35.0	49.6	58.7	56.3	64.7	57.3
	12	22.9	38.1	34.9	34.1	32.5	53.4	49.5	56.0	66.7	56.4

yields for comparison of varieties, rates of seeding, and row spacings in combinations of two each are shown in Table 4. Since the F values of the interactions are not significant, there are no significant differences among these means, nor among the means of the variety-rate-spacing combinations shown in Table 1.

DISCUSSION OF RESULTS

The mean yield of all plats in the experiment at Beaumont exceeded that of the experiment at Crowley by 21.7 bushels. The larger yields

TABLE 1.—*Continued.*

Rate of seeding, lbs.	Row spacing, in.	Acre yield in bushels									
		Crowley, La., blocks					Beaumont, Texas., blocks				
		1	2	3	4	Mean	1	2	3	4	Mean
					Blue Rose						
60	6	26.9	27.5	26.4	27.6	27.1	41.5	47.4	37.3	47.5	43.4
	8	25.3	24.0	23.9	28.0	25.3	42.4	43.3	39.9	46.9	43.1
	10	21.8	27.2	20.5	33.0	25.6	31.4	49.5	45.9	52.7	44.9
	12	24.3	24.3	24.8	26.1	24.9	39.6	46.0	41.5	41.7	42.2
80	6	28.0	32.9	26.8	28.1	29.0	50.2	43.3	43.9	51.8	47.3
	8	23.5	38.1	24.3	30.9	29.2	46.5	46.9	45.0	49.2	46.9
	10	22.7	29.1	23.7	26.1	25.4	39.4	40.9	39.8	52.2	43.1
	12	21.1	27.2	23.2	26.9	24.6	40.5	47.1	45.1	50.2	45.7
100	6	29.7	28.7	31.6	29.1	29.8	42.7	41.3	45.3	44.0	43.3
	8	28.4	32.7	28.4	25.3	28.7	42.7	42.6	42.5	40.7	42.1
	10	28.0	25.9	23.8	30.4	27.0	54.8	48.5	43.9	45.5	48.2
	12	21.1	25.6	27.5	30.1	26.1	51.2	39.1	44.1	40.9	43.8
120	6	28.4	28.8	31.6	27.1	29.0	37.7	43.6	40.1	43.7	41.3
	8	26.0	27.3	27.6	28.8	27.4	44.1	44.7	35.3	39.9	41.0
	10	24.2	29.5	25.8	24.5	26.0	39.5	38.4	41.5	44.7	41.0
	12	19.5	24.8	29.6	28.5	25.6	43.6	40.3	42.8	45.3	43.0
					Rexoro						
60	6	33.7	50.2	30.9	46.5	40.3	44.7	55.8	60.3	52.5	53.3
	8	47.5	39.9	36.0	37.5	40.2	54.3	63.0	64.4	44.5	56.6
	10	43.2	44.0	31.5	42.1	40.2	52.7	59.2	64.9	45.5	55.6
	12	34.4	38.1	29.3	28.8	32.7	60.3	68.7	55.5	53.0	59.4
80	6	38.4	40.0	28.3	39.2	36.5	53.5	62.3	58.7	61.8	59.1
	8	38.3	38.5	30.5	41.6	37.2	61.0	60.0	63.6	61.8	61.6
	10	34.6	35.1	29.3	36.3	33.8	59.2	62.6	61.8	50.8	58.6
	12	41.1	35.7	18.4	54.2	37.4	50.2	57.6	56.6	61.6	56.5
100	6	37.3	39.2	36.7	41.1	38.6	59.0	59.0	64.0	48.5	57.6
	8	37.9	39.1	27.2	44.9	37.3	55.8	63.2	59.8	62.0	60.2
	10	37.8	32.7	29.6	39.1	34.8	59.0	64.0	60.2	63.6	61.7
	12	34.1	28.8	32.8	47.5	35.8	59.1	63.8	62.2	59.6	61.2
120	6	31.2	39.5	39.7	30.1	35.1	55.9	58.3	56.2	62.2	58.2
	8	32.3	41.3	42.3	41.1	39.3	53.0	62.7	57.8	57.6	57.8
	10	32.2	41.0	38.3	27.1	34.7	49.5	61.6	58.0	60.1	57.3
	12	31.2	44.0	33.9	25.3	33.6	59.4	57.5	61.2	59.5	59.4
General mean						32.8					54.6

at Beaumont were probably due to a higher state of soil fertility and are in line with other yields obtained from the same varieties.

The analysis of the main plats shows an essential agreement between the two tests. There was greater soil variation at Crowley as shown by the significant variance among blocks. This may be due in part to the condition brought about by leveling the old levees in the

TABLE 2.—*Variance in the variety-rate-spacing experiment of 1936.*

Variation due to	Degrees of freedom	Sum of squares	Mean square	F
	Crowley, Louisiana			
Block	3	668.70	222.90	3.98*
Variety	3	3,410.90	1,136.97	20.30†
Rate of seeding	3	251.75	83.92	1.50
Variety × rate	9	414.72	46.08	0.82
Error (a)	45	2,519.98	56.00	—
Main plats	63	7,266.05	115.33	6.54†
Row spacing	3	510.97	170.32	9.66†
Spacing × variety	9	64.42	7.16	0.41
Spacing × rate	9	70.18	7.80	0.44
Spacing × variety × rate	27	335.24	12.42	0.70
Error (b)	144	2,540.27	17.64	—
Total	255	10,787.13		
	Beaumont, Texas			
Block	3	427.92	142.64	2.64
Variety	3	9.971.03	3,323.68	61.41†
Rate of seeding	3	172.90	57.63	1.06
Variety × rate	9	430.90	47.88	0.88
Error (a)	45	2,435.43	54.12	—
Main plats	63	13,438.18	213.30	10.91†
Row spacing	3	18.16	6.05	0.31
Spacing × variety	9	458.96	51.00	2.61
Spacing × rate	9	283.80	31.53	1.61
Spacing × variety × rate	27	606.57	22.47	1.15
Error (b)	144	2,815.52	19.55	—
Total	255	17,621.10		

*Exceeds the 5% point.
†Exceeds the 1% point.

TABLE 3.—*Mean yields in bushels per acre for varieties, rates of seeding, and row spacings.*

Variety	Acre yields in bushels		Rates of seeding, lbs. per acre	Acre yield in bushels		Spacing between rows, in.	Acre yield in bushels	
	Crowley	Beaumont		Crowley	Beaumont		Crowley	Beaumont
Caloro	33.0	58.8	60	31.7	53.1	6	34.6	54.2
Fortuna	34.6	57.3	80	32.0	55.0	8	33.6	54.4
Blue Rose	26.9	43.8	100	34.0	55.0	10	32.3	54.9
Rexoro	36.7	58.4	120	33.6	55.0	12	30.8	54.7

experimental area. The F value obtained for varietal differences was much greater in both experiments than is necessary for odds of 99:1.

TABLE 4.—*Mean yields in comparison of varieties, rates of seeding, and spacings in combinations of two each.*

	Crowley				Beaumont			
	Cal-oro	For-tuna	Blue Rose	Rex-oro	Cal-oro	For-tuna	Blue Rose	Rex-oro
				Varieties and Rates				
60 lbs. per acre	29.7	32.8	25.7	38.4	58.1	54.8	43.4	56.2
80 lbs. per acre	31.9	32.9	27.0	36.2	58.2	57.2	45.8	58.9
100 lbs. per acre	34.5	36.9	27.9	36.6	57.2	58.2	44.4	60.2
120 lbs. per acre	35.8	35.9	27.0	35.7	61.4	59.0	41.6	58.2
				Varieties and Spacings				
6-inch	34.8	37.1	28.7	37.6	55.6	60.4	43.8	57.0
8-inch	33.6	34.7	27.7	38.5	59.4	55.6	43.3	59.0
10-inch	33.2	34.1	26.0	35.9	60.0	56.9	44.3	58.3
12-inch	30.4	32.6	25.3	34.9	59.9	56.2	43.7	59.1
				Rates and Spacings				
	60-lb. rate	80-lb. rate	100-lb. rate	120-lb. rate	60-lb. rate	80-lb. rate	100-lb. rate	120-lb. rate
6-inch	32.9	34.0	35.7	35.6	53.5	52.7	53.2	56.5
8-inch	32.8	32.6	34.3	34.7	52.7	55.8	54.1	54.8
10-inch	32.2	30.8	33.3	33.0	53.7	54.6	57.5	53.7
12-inch	28.8	30.7	32.6	31.1	52.6	56.1	55.1	55.1

Rate differences were not significant. In previous rate of seeding tests conducted at Crowley the 60-pound rates usually yielded somewhat less than the 80 and 100 rates (2). The interaction of varieties and rates also gave F values much below those necessary for odds of 19:1 that the differences were significant. Since the interaction of varieties and rates was not significant, it is clear that varietal differences were expressed equally over the full range of the rates of seeding used.

Analysis of the sub-plat yields for the purpose of comparing row spacings revealed that the spacing differences were highly significant at Crowley, but were not significant at Beaumont. The fact that other nursery yields from rows spaced 12 inches apart at Crowley have also averaged distinctly lower than the same varieties in field plats in which the spacing was 8 inches appears to confirm the Crowley results in this experiment. The spacing x variety and the spacing x rate interactions were not significant at either station, nor was the variety-rate-spacing interaction. This shows that the varieties responded in the same manner to the various combinations of rates of seeding and spacing.

Coefficients of variability computed from data on spacings in three years are shown in Table 5. In 1934 a less efficient experimental design was used. In 1935 two varieties only were included at Beaumont and certain plats were missing at Crowley, but the experiment was of the same design as the complete experiment of 1936. The coefficients of variability for spacings in 1934 were of about the same magnitude at both stations. In 1934 the experiments were on rather infertile soil

TABLE 5.—*Coefficients of variability from row spacing experiments, 1934 to 1936, inclusive.*

Location	Coefficient of variability, spacing in inches				
	6	8	10	12	Experiment
			1934		
Crowley	18.3	17.0	15.0	21.1	18.1
Beaumont	15.3	17.3	16.6	22.2	17.9
			1935		
Crowley	20.2	19.4	19.9	22.6	20.6
Beaumont	14.0	12.5	14.6	14.9	13.9
			1936		
Crowley	18.1	18.7	18.8	22.4	19.8
Beaumont	15.2	15.9	15.1	15.1	15.2

at both stations. At Crowley there was general agreement in magnitude over the 3-year period. Coefficients from the Beaumont data, however, were distinctly lower in 1935 and 1936 than in 1934 for the 12-inch spacing. A more accurate distribution of seed may have in part accounted for this decrease in variability. Another possible factor was the higher state of fertility of the area used which would promote a greater equalizing growth of plants adjacent to missing areas. At Crowley rather dry conditions at time of emergence were partly responsible for somewhat uneven stands. They were, however, equal to stands ordinarily obtained in nursery tests.

Similar experiments, using transplanted rice, have been reported by Chakravertti, Bose, and Mahalanobis (1) in India. No significant differences were found among 6-inch, 9-inch, and 12-inch spacings between hills nor for one, two, or two to four plants per hill, except that yields from close spacing and a larger number of plants per hill were significantly higher when planting was delayed. Peh (3) in China, reporting on tests conducted on three crops grown in two years, found that the closer spacings gave significantly higher yields. Differences in numbers of plants per hill were not significant, but the interaction of spacing and number of plants were significant.

SUMMARY

Among nursery plats of approximately the same area, increasing the number of rows per plat, with a concomitant increase in the proportion of the plat harvested, increased the yields of rice and reduced the variability somewhat in experiments at Crowley, La., but had no significant effect at Beaumont, Texas.

Highly significant varietal differences were found at both stations by the analysis of variance. Rates of seeding varying from 60 to 120 pounds per acre did not affect the yields. At Crowley the plats with 6-inch intervals between rows gave significantly higher acre yields than did plats with wider spacings. On more fertile soil at Beaumont

spacing the rows from 6 to 12 inches apart did not influence acre yields. Where the yields of nursery plats, grown in rows spaced 12 inches apart, are consistently lower than those of the same varieties grown in field plats, the results at Crowley indicate that by allowing less space between the rows and by harvesting a larger proportion of the plat the nursery yield may be increased. This practice, however, would require more labor in seeding, harvesting, and threshing, and would make roguing more difficult.

Since none of the interactions was significant at either station, it appears that the varietal differences were expressed equally over the full range of seeding rates and spacings.

Coefficients of variability show that at Crowley the three-row plats with a 12-inch row spacing and with only the one center row harvested were slightly more variable than were plats of the same or similar size in which the rows were spaced more closely and two to four of the inside rows were harvested. At Beaumont the plat variability was practically the same regardless of the spacing between rows.

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THE INHERITANCE OF PERICARP TENDERNESS IN SWEET CORN[1]

I. J. JOHNSON and H. K. HAYES[2]

THE present-day method of corn breeding has met with outstanding success in its application to sweet corn improvement. Many canning companies are now utilizing hybrids exclusively in the production of their commercial canning crop. The superiority of hybrids, in uniformity, productiveness, and in many cases resistance to destructive diseases, has resulted in this rapid change from open-pollinated varieties to hybrid strains. The improvement of quality in hybrids also ranks as a major problem. While many of the "quality" attributes in sweet corn are difficult to evaluate on a numerical basis, pericarp tenderness appears to lend itself to fairly accurate measurement. The need for tender pericarp hybrids is of special importance in meeting the demand for types suitable for whole ear as well as in whole kernel canning methods.

Detailed histological studies have been reported by Haddad[3] showing the changes which occur in the pericarp tissue during the development of the endosperm in sweet corn. Doxtator[4] has made a recent report of previous studies at the Minnesota Agricultural Experiment Station on the measurement of quality in sweet corn.

The present paper will present studies conducted since 1934 pertaining to the inheritance of pericarp tenderness in sweet corn.

MATERIAL AND METHODS

Among the inbred lines used in the sweet corn improvement program, the strains obtained from the Crosby variety have exhibited a greater degree of pericarp toughness than those from 8-rowed Golden Bantam. The objection to the use of the Crosby variety has been based largely upon the toughness of its pericarp. A 4-year selfed Crosby inbred line, culture 1–30, used as one of the parents in Minhybrid 204, was selected as a typical tough pericarp line. An extremely tender pericarp, white endosperm, open-pollinated variety of unknown origin, was obtained from H. M. Hayes of Granby, Conn., who has grown it for home use for many years. This variety has a more tender pericarp than the most tender lines from Golden Bantam.

The measurement of pericarp tenderness was made with a puncture test machine similar to the one first described by Culpepper and Magoon[5]. All ears

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[2]Assistant Professor and Chief, respectively.

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were tested in hand-pollinated ears at 20 days after pollination or in open-pollinated ears 20 days after the first appearance of silks on the individual plants. Five or six kernels near the center of the ear were punctured to obtain an average value for any particular ear. This method was found to be rapid and applicable also to ears punctured on the plant when it was necessary to grow the ears to complete maturity.

The data included in this paper consist of measurements of puncture test values of the tough and tender pericarp parents, 1–30 and H, for the period 1934–37; the F_1 cross (1 × H) for the period 1934–35; the F_2 generation for the 3-year period 1935–37; and backcrosses to the tender and tough pericarp parents in 1935. In addition to these data, a study was made in 1937 to test the breeding behavior of 34 F_3 lines and of 42 first generation selfed progenies from first backcrosses to the tender parent. From 40 to 60 ears were puncture tested in each progeny row. The plants were marked with a different colored tag to designate their date of first emergence of silks and the open-pollinated ears were puncture tested 20 days later. Seven rows of each of the two parents were also grown and tested as individual rows for the purpose of studying comparative variability of the parents in relation to the F_3 and first year selfed progenies from the first backcross.

Typical examples, from the backcrosses used in the breeding studies for pericarp tenderness, will be used to illustrate the effect of selecting for tenderness in a backcross to the tough pericarp parent and to show the extent of recovery of the genotype of the tender parent in backcrosses to the tender parent.

The puncture tests of ears used in the breeding studies were made on the plant by stripping back a portion of the husks, puncturing the desired number of kernels, and replacing the husks to prevent premature drying of the kernels. The ear bag was also replaced further to protect the ear from damage. The data on inheritance of pericarp tenderness are summarized in two parts as somewhat different methods were used in taking the data. From 1934 to 1936, inclusive, puncture tests were made in the field on the plants and the occasional widely deviating measurement on a particular ear was discarded providing it was not obtained again in a second reading. The machine used for this work was more finely graduated than for the 1937 studies.

In the 1937 studies no readings were discarded. The ears were harvested and brought into the laboratory before taking the puncture readings. The data presented in Fig. 1 and Table 2 were taken in 1937 as described. All other data were taken in the field and the more finely graduated puncture test machine was used.

EXPERIMENTAL RESULTS

INHERITANCE OF PERICARP TENDERNESS

From the summary of the data on the inheritance of pericarp tenderness given in Table 1 it is apparent that the two parents, cultures H and 1–30, were consistently different in pericarp tenderness during the 3-year period 1934–36. The average difference in puncture test values between them was slightly over 100 units. The Crosby inbred line 1–30 gave a somewhat more consistent puncture test value from year to year and considerably less variability than the H parent, an open-pollinated variety. The F_1 cross was made with pollen bulked from several plants of the tender parent to insure a representative average of its genotype. The average values for the F_1 crosses studied in 1934 and 1935 were approximately intermediate between the two

parents not only in the mean puncture test value for the population but also in respect to variability. The frequency distribution of the F_1 population and its mean would suggest a lack of dominance for either tender or tough pericarp.

The F_2 data obtained on a rather limited basis in 1935 and more extensively in 1936 do not make it possible to decide regarding the number of genes which condition pericarp tenderness. While the F_2 is somewhat more variable than F_1, the range in F_2 in 1935 extended over only two more classes in the frequency table than did the F_1. The coefficient of variability obtained in the F_2 population exceeded that for the F_1 generation and also the open-pollinated tender pericarp variety during the comparable period in 1935 and 1936.

The backcross to the tender pericarp parent in 1935 gave a mean value midway between the tender pericarp parent and the F_1 cross grown during the same season, indicating, as would be expected, the tendency partially to recover the genotype of the tender pericarp parent.

The backcross to the tough pericarp parent gave a higher mean puncture test value than the backcross to the tender parent but failed to show the partial recovery of the genotype of the tough parent. The mean value of 332 in this backcross was approximately equal to that of the F_1 cross grown during the same year rather than midway between the F_1 cross and the tough pericarp parent.

The data for 1937 for the two parents and an F_2 generation is given in Fig. 1. Larger numbers of plants were tested in this study, the curves given being on the basis of an n value for H, 1–30, and the F_2 of 390, 299, and 430, respectively. Mean values were 293 ± 1.19, 387 ± 1.54, and 352 ± 1.99 for the parents and F_2. In this study the F_2 mean is somewhat higher than the average of the parents and some ears were obtained with slightly higher and lower puncture values than for the tough and tender pericarp parents, respectively.

The breeding behavior of F_2 plants and first year selfed progeny of first backcrosses to the tender parent was determined by puncture testing from 40 to 60 ears from their progeny rows. Seven rows of each parent were also tested separately to compare the variability within and between rows of the parents in relation to the progenies. It should be remembered that these data and those given in Fig. 1 are taken in a comparable way, while the rest of the data were taken as described with a puncture test machine with finer graduations. The data from this test, summarized in Table 2, show that the coefficient of variability for rows of culture 1–30 ranged from 5 to 8% and for the open-pollinated H parent variety from 5 to 12%. Among the 34 F_3 lines from the cross of 1–30 × H, 12 progeny rows were no more variable than the 1–30 inbred parent, and all but two no more variable than the H parent, although their means differed greatly. The data from the F_3 lines suggest that relatively homozygous tough pericarp strains were obtained more frequently than homozygous tender strains since 5 of the 12 low variability lines had the same mean puncture test value as the tough parent. No strains were obtained having as low a mean value as the tender parent with a coefficient of variation of the same magnitude as H. The recovery in F_3 of relatively

TABLE 1.—*Frequency distribution of puncture test values of parents, F_1, F_2, and backcrosses to the two parents from a cross of tender × tough pericarp sweet corn, 1934–36.*

Culture	Year	Puncture test values										Total	Mean	C.V.
		240	260	280	300	320	340	360	380	400	420			
H parent	1934	11	18	19	11	5	1	—	—	—	—	65	275	9.0
	1935	—	13	40	46	13	7	—	—	—	—	119	293	6.9
	1936	14	28	33	6	1	—	—	—	—	—	82	268	6.7
I–30 parent	1934	—	—	—	—	—	—	4	26	42	5	77	392	3.5
	1935	—	—	—	—	—	—	11	40	37	4	92	387	3.9
	1936	—	—	—	—	—	—	11	46	43	—	100	386	3.4
(I–30×H) F_1	1934	—	—	—	5	27	31	14	7	1	—	85	339	6.4
	1935	—	—	—	6	40	44	4	1	—	—	95	330	4.4
(I–30×H) F_2	1935	—	—	1	9	23	20	16	8	2	—	79	338	7.8
	1936	—	3	19	40	40	24	8	2	—	—	136	314	7.8
(I–30×H) × H	1935	—	3	15	28	22	13	7	3	—	—	91	313	8.8
(I–30×H) × I–30	1935	—	—	4	12	23	23	15	4	1	—	82	332	7.7

homozygous lines having a mean puncture test value intermediate to the two parents strongly suggests that several factor pairs were involved. The parent-progeny correlation between puncture values of 34 F_2 plants and the mean of their F_3 progeny was .64, a highly significant coefficient.

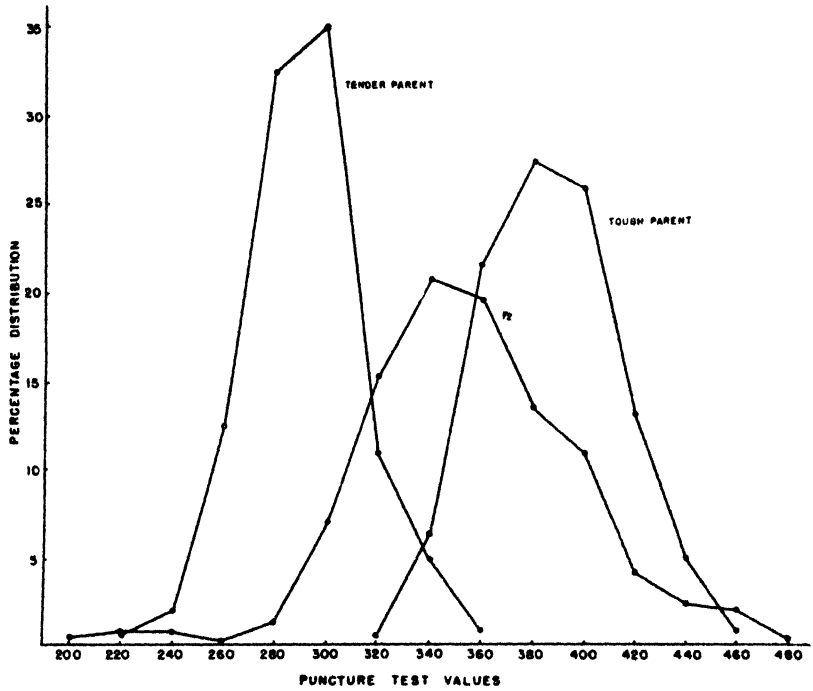

FIG. 1.—Percentage distribution of the two parents and the F_2 population from a cross between a tender pericarp variety and a tough pericarp inbred line, 1937.

In the first year selfed progenies of backcrosses to the tender pericarp parent, a smaller percentage of lines with a coefficient of variability of from 5 to 8 were recovered as would be expected on the basis of the coefficient of variability of the H parent. The occurrence of relatively homozygous lines having a mean puncture test value greater than the tender parent again suggests that several factor pairs are concerned in the inheritance of pericarp tenderness.

From the first selfed progenies of the first backcross to H there were 16 progenies out of 42 with means puncture test values as low as the rows of the H parent. Two of these rows were more variable than H as determined by the coefficient of variability grouping. None of the 42 progenies gave means as high as the seven rows of the tough parent. These data indicate that tender pericarp lines may be obtained relatively easily after backcrossing. The difficulty of determining how many factors are involved is due partially to the lack of homozygosity of the H parent.

TABLE 2.—*Frequency distribution of means for individual rows of parent lines, F_3 progenies, from first year selfed progenies from first backcrosses to the tender pericarp parent classified according to variability as expressed by the coefficient of variation, 1937.*

Culture	C.V.	Average puncture test values								
		260	280	300	320	340	360	380	400	Total
1–30 parent	5–8	—	—	—	—	—	—	5	2	7
H parent	5–8	—	1	2	—	—	—	—	—	3
H parent	9–12	—	1	3	—	—	—	—	—	4
Total	——	—	2	5	—	—	—	—	—	7
(1 × H) F_2 parent ears	——	—	—	5	14	6	6	3	—	34
(1 × H) F_3 lines	5–8	—	—	—	1	1	5	4	1	12
(1 × H) F_3 lines	9–12	—	—	—	3	2	7	4	4	20
(1 × H) F_3 lines	13–16	—	—	1	1	—	—	—	—	2
Total	——	—	—	1	5	3	12	8	5	34
(1 × H) × H parent ears	——	2	12	15	9	4	—	—	—	42
(1 × H) × H first year selfed	5–8	—	—	1	2	1	2	—	—	6
(1 × H) × H first year selfed	9–12	—	2	11	9	6	3	—	—	31
(1 × H) × first year										
(1 × H) × H first year selfed	13–16	—	—	1	1	1	—	—	—	3
(1 × H) × H first year selfed	17–20	—	—	1	1	—	—	—	—	2
Total	——	—	2	14	13	8	5	—	—	42

The parent-progeny correlation between puncture values of the 42 first backcrossed plants and their first year selfed progenies was .56.

BREEDING FOR PERICARP TENDERNESS

From the regular breeding studies for pericarp tenderness conducted at University Farm, a typical example will be presented to illustrate the effect of selection for pericarp tenderness in a series of backcrosses to the tough parent. This backcross was planned for the purpose of improving the pericarp tenderness of the Crosby inbred line 1–30 without greatly modifying its proved combining ability. Other backcrosses have been selected also to show the recovery of the genotype of the tender parent in a cross made for the purpose of transferring the gene for yellow endosperm from a Golden Bantam inbred line, culture 78, to the tender H strain.

A summary of puncture test values of the parents, three backcrossed generations to the tough pericarp parent, and two backcrossed generations to the tender parent is given in Table 3. It is evident that selection for tenderness in a backcross to the tough parent has been effective during two generations in maintaining a heterozygous population comparable in distribution to the first segregating backcross. The backcrosses of $(1xH)1$, $(1xH)1_2$, and $(1xH)1_3$ are all remarkably similar not only in their frequency distribution and means but also in the magnitude of their coefficient of variation, indicating that the

same relative level of heterozygosity has been maintained throughout three generations when the backcrosses were made to the tough parent. The $(lxH)1_2$ backcross in 1936 represents a sample of the progeny from 24 ears of (lxH)1 pollinated with 1–30. These backcrossed ears, selected for planting, ranged in puncture test value from 277 to 320. Similarly, the $(lxH)1_3$ backcross in 1937 was obtained from the progeny of 41 ears of the $(lxH)1_2$ population pollinated again with 1–30 and selected from the tender pericarp ears ranging from 283 to 332. The distribution of the backcrossed progenies show a fairly high percentage of individuals more tender than the 1–30 parent. These tender pericarp ears apparently have essentially the same genotype as the F_1 cross as shown by the nature of their comparable segregation when crossed to the tough pericarp parent. The results from this backcross study would therefore indicate that the inheritance of pericarp tenderness in sweet corn is sufficiently simple so that extremely tender strains may be used successfully in backcrosses as a means of improving tough pericarp inbred lines that have other desirable characters. The populations used in these studies have been sufficiently small so that it has been possible to conduct several backcrosses during a single season. At University Farm in 1937, approximately 1,500 ears were puncture tested on the plant among the eight backcrosses and parents used in the program of breeding for pericarp tenderness.

In the backcrosses made to the tender pericarp H parent the data in Table 3 show a rapid recovery of the genotype for tenderness. In the first segregating backcross of (78xH)H in 1936 the mean value of the population as well as the coefficient of variability is greater than the recurrent parent. The second backcrossed population, $(78xH)H_2$, was obtained from ears in the former generation which were as tender as the H parent. Consequently, since they were backcrossed to the tender pericarp parent, it would be expected that the distribution in 1937 would be essentially the same as the recurrent parent. The results obtained in the second backcross show a very close agreement with expectation. The actual mean and the coefficient of variation of the second backcrossed progenies are only slightly higher than that of the tender parent, indicating nearly a complete recovery of its genotype in two backcrossed generations when selection for tenderness was practiced.

RELATION OF PUNCTURE TEST VALUES TO STAGE OF MATURITY AND AGE OF UNPOLLINATED SILKS

As previously indicated, a constant period of time was selected between pollination and puncture testing. A period of 20 days was chosen because under average conditions in Minnesota with the types of sweet corn grown the material has reached the optimum stage of maturity for canning. On the average, sweet corn kernels contain approximately 70% moisture 20 days after pollination—a moisture percentage considered by canning companies to be nearly optimum for a high-quality canned product.

In 1936 a study was made to determine the daily rate of change in puncture test values beginning at 18 days and extending to 22 days

TABLE 3.—*Frequency distribution of puncture test values of ears from backcrosses to the tough pericarp parent and backcrosses to the tender pericarp parent with selection for tenderness.*

Culture	Year	Puncture test values										Total	Mean	C. V.
		240	260	280	300	320	340	360	380	400	420			
$(1 \times H) 1$	1935	—	—	4	12	23	23	15	4	1	—	82	332	7.8
$(1 \times H) 1_2$	1936	—	—	5	14	36	40	26	13	2	—	136	337	7.7
$(1 \times H) 1_3$	1937	—	—	2	28	43	65	40	15	6	—	199	338	7.6
1–30 parent	1935	—	—	—	—	—	—	11	40	37	4	92	387	3.9
1–30 parent	1936	—	—	—	—	—	—	11	46	43	—	100	386	3.4
1–30 parent	1937	—	—	—	—	—	2	16	8	—	—	26	365	3.2
H—parent	1936	14	28	33	6	1	—	—	—	—	—	82	268	6.7
H—parent	1937	1	19	16	10	2	—	—	—	—	—	48	277	6.6
$(78 \times H) H$	1936	3	17	27	22	9	3	—	—	—	—	81	286	8.0
$(78 \times H) H_2$	1937	1	40	37	21	8	0	1	—	—	—	108	280	7.4
78 parent	1936	—	—	1	7	—	—	—	—	—	—	8	298	2.4
78 parent	1937	—	—	—	6	18	5	1	—	—	—	30	321	4.5

after pollination. Two Golden Bantam single crosses were used, Minhybrid 202, a relatively early hybrid, and Minhybrid 201, a somewhat later cross. This study was made by selecting 25 plants of a uniform stage of maturity for each variety and puncture testing these ears daily starting 18 days after pollination. Since the same ears were

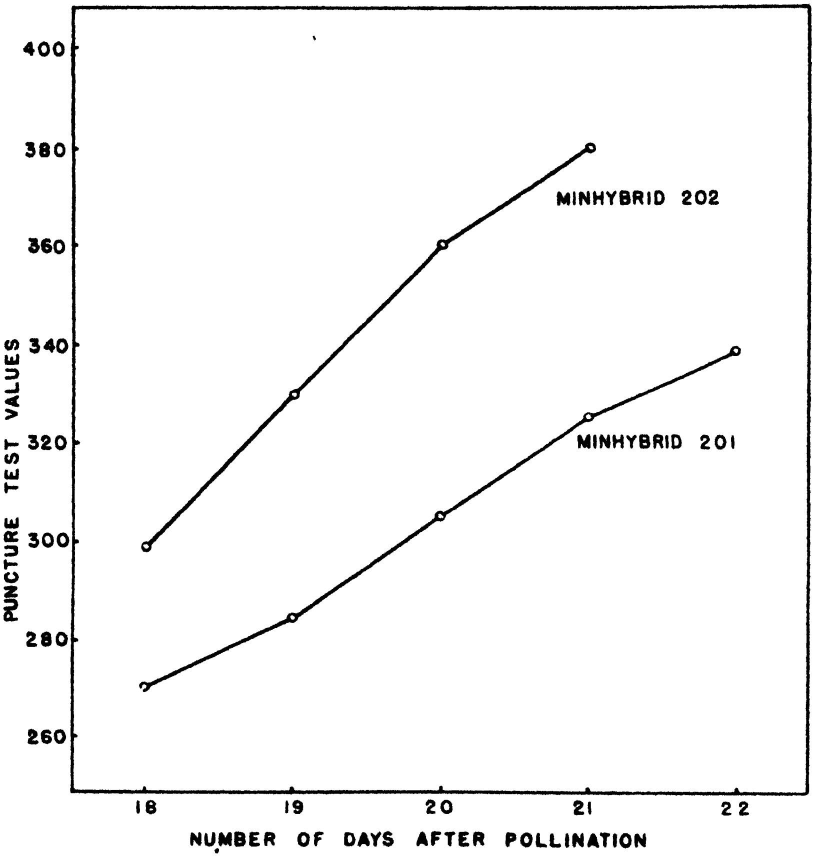

FIG. 2.—Rate of daily change in pucture test values in relation to the number of days after pollination.

used each day, the differences obtained should be due chiefly to progressive changes in pericarp toughness. In making the puncture tests on the plant, only a small portion of the husk was stripped back to expose the kernels. The husks were carefully replaced after the puncture readings had been obtained and the ears covered with a parchment bag to prevent premature loss in moisture. The study with Minhybrid 202 was terminated after the 21st day because the values for some ears were near the maximum that could be obtained with the tester used.

The results of this study, shown in Fig. 2, emphasize the importance of making all puncture test readings for a given population at

the same interval of time after pollination. The daily rate of change for Minhybrid 202 from 18 to 20 days after pollination was about 30 units and for Minhybrid 201 approximately 20 units from the 18th to the 21st day. Both hybrids tend to show a smaller daily change for the last day in which values were obtained. Minhybrid 201, the later maturing cross, also had a consistently smaller daily change than Minhybrid 202.

During the progress of these studies it was apparent that factors other than the number of days after pollination influenced the puncture test values obtained. Within the inbred lines, for example, some ears appeared to be relatively more mature than others at the same number of days after pollination. In the pollination technic employed prior to 1937, crosses or selfs were made every two or three days within a given population until the desired number of selfed ears had been obtained. By this method the silks of some ears may have appeared three days and others only one day prior to pollination. A study was made, therefore, to determine if any relationship might exist between the age of the silks at pollination time and the puncture test value. In Minhybrid 202 a fairly large number of ears were bagged and the date of silk emergence recorded for each plant. Pollinations by hand were then made on three groups of 20 to 25 plants each. In one group the silks had emerged five days prior to pollination, in another group three days, and in the third group pollination was made on the day the silks emerged. All pollinations were made for the three groups on the same day and puncture test values obtained 20 days later. The results, shown in Fig. 3, indicate clearly that the puncture test values may be greatly modified by the age of the silks at the time of pollination. These results would indicate that the pericarp tissue may develop for a period of at least five days without fertilization.

SUMMARY

1. In a study of the inheritance of pericarp tenderness in sweet corn, data were obtained from a cross between a very tender, open-pollinated variety and a tough pericarp Crosby inbred line. The two parents used in the cross showed a consistent difference of approximately 100 units as measured with a puncture tester, while the F_1 cross between the tender and tough parents was approximately intermediate in puncture test value and also in its coefficient of variability.

2. In studies of the F_2 carried on in 1935 and 1936 with populations of 79 and 136, respectively, segregation occurred with a coefficient of variability greater than that of the F_1 and the H parent. In 1937, from a population of 430 F_2 plants in comparison with 390 of the tender pericarp and 299 of the tough pericarp parent, the F_2 slightly exceeded the range of the tender pericarp parent in tenderness and of the tough pericarp parent in toughness.

3. In a study of F_3 progeny rows and in first year selfed lines from backcrosses to the tender parent, lines were obtained with as low a coefficient of variations as the inbred, tough pericarp parent. The recovery of relatively pure lines having an average puncture test value in the classes intermediate between the parents suggests that sev-

eral factor pairs condition pericarp tenderness. There was only one line in F_3 out of 34 with as low a mean as that of the H parent. Sixteen of 42 first year selfed lines from the first backcross gave as low means as obtained from the rows of the tender pericarp parent.

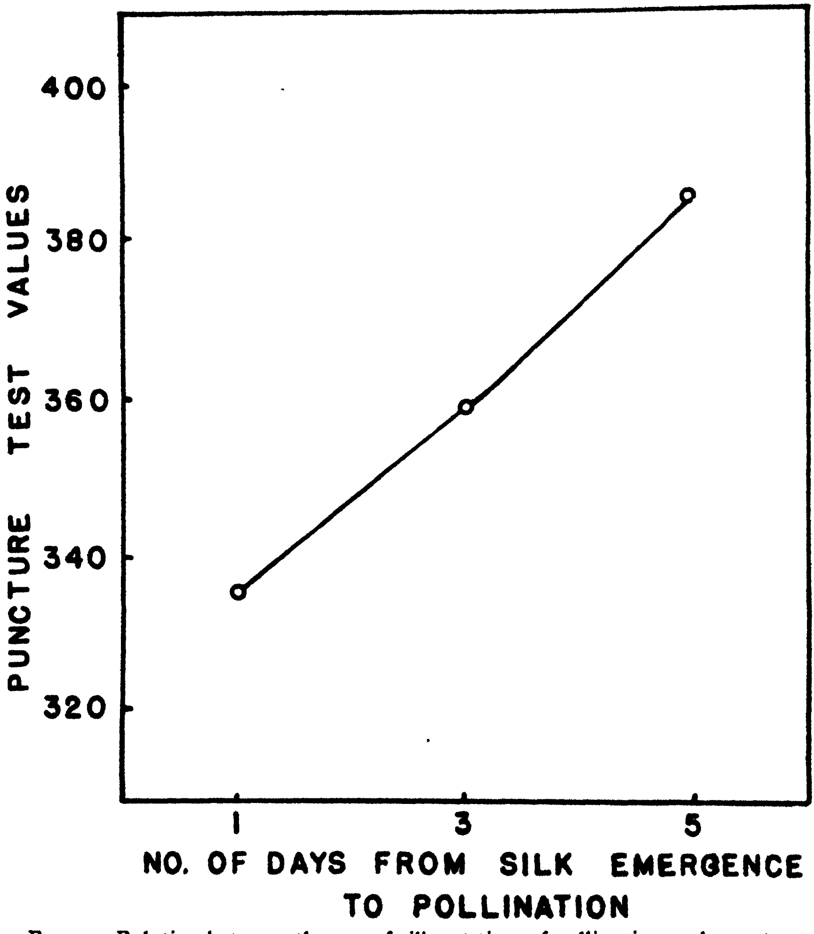

FIG. 3.—Relation between the age of silks at time of pollination and puncture test value.

4. In backcrosses to the tough pericarp parent, selection for tenderness during two segregating generations has maintained the same range in distribution of puncture test values as that obtained when the F_1 was backcrossed to the tough parent. These results indicate that the genes for pericarp tenderness from the tender parent have been successfully carried in a heterozygous condition.

5. In backcrosses to the tender pericarp parent, selection for tenderness has apparently been effective in an almost complete recovery of the genotype of the tender parent in the second backcrossed generation.

6. In a study made to determine the daily changes in puncture test values from the period 18 to 22 days after pollination, a daily increase of approximately 30 units was obtained in one cross and 20 units in a later maturing hybrid.

7. Puncture test values from ears pollinated when the silks had been emerged for 1, 3, and 5 days showed an increase of over 20 units in puncture test for each interval of two days after the silks had emerged. These results indicate that the pericarp in sweet corn continues to develop without fertilization for a period of at least five days.

THE ABSORPTION AND UTILIZATION OF NITRATE NITROGEN DURING VEGETATIVE GROWTH BY ILLINOIS HIGH PROTEIN AND ILLINOIS LOW PROTEIN CORN[1]

IRWIN R. HOENER and E. E. DETURK[2]

IN 1896 the Illinois Agricultural Experiment Station began a series of experiments to determine whether the chemical composition of corn could be altered by selection (20).[3] A variety known as Burr's White was used as the foundation stock and selections were made, based upon chemical analysis, for high protein[4] and low protein content of the grain at maturity. These two strains have since been termed Illinois High Protein and Illinois Low Protein. They have undergone 40 generations of continuous selection.[5]

Beginning with a mean protein content in the grain of 10.92% in 1896, a comparatively wide spread has been attained between them. For instance, the mean values for the high protein strain the past 3 years were, respectively, 23.79, 17.71, and 21.63%, and for the low protein strain, 10.75, 5.90, and 8.01%. Fig. 1 shows the mean protein content of the grain year by year and also the highest and lowest variant among the individual ears analyzed of each line. Every year since 1921 the lowest high-protein variant has been higher than the highest low-protein variant, that is, they have never crossed.

The purpose of the investigation reported in this paper was to determine the effect of the nitrate nitrogen concentration in the culture medium upon nitrogen absorption and assimilation during vegetative growth of plants of the high- and low-protein strains, separating the total nitrogen of these plants into the various groups of compounds which are concerned in nitrogen metabolism.

The literature contains accounts of many studies which relate, to some extent, to the object of this investigation. The effectiveness of a breeding program to modify the chemical composition of corn has been demonstrated (14, 18, 19, 35, 36). Many studies (1, 2, 4, 5, 8, 11, 15, 23, 32, 33) have furnished interesting observations on the nitrogen metabolism of plants. Several workers (3, 6, 16, 21, 22, 26, 27, 31) have demonstrated the effect of environment on composition as well as on growth, and some recent papers (9, 10, 28) report on conditions which affect the assimilation of ammonium and nitrate ions. In none of the investigations referred to was there available plant material with a definite hereditary difference in nitrogen content among plants within the same species. An opportunity to observe differences in

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[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 11, 1937.

[2]Assistant and Professor in Soil Fertility, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 242.

[4]The term "protein" in this instance refers to the total nitrogen multiplied by the conventional factor 6.25.

[5]Acknowledgment is accorded to Dr. Louie H. Smith, who conducted this investigation during the first 25 years.

nitrogen utilization by such plants, was provided by Illinois High Protein and Illinois Low Protein strains of corn.

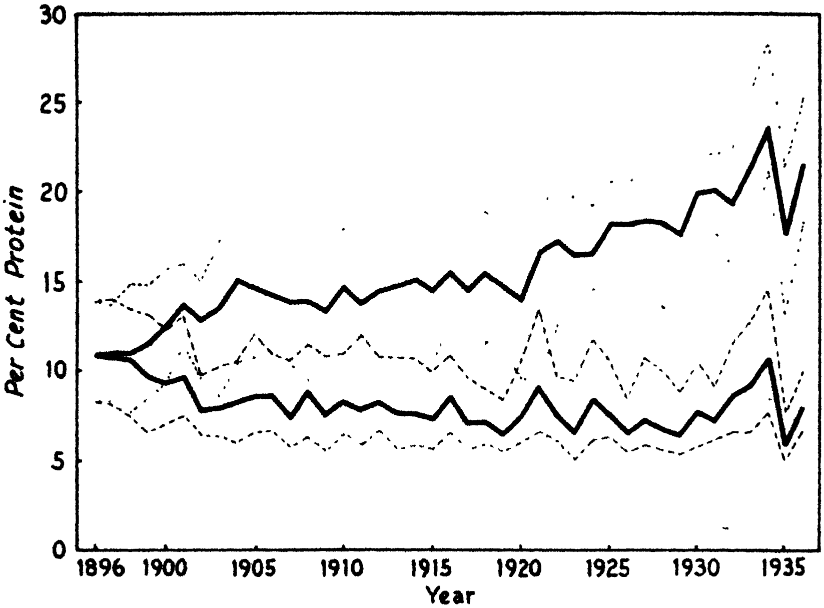

FIG. 1.—Mean yearly protein content of Illinois High and Low Protein corn, with lowest and highest variant of each line. (Courtesy Dr. C. M. Woodworth.)

MATERIALS AND METHODS

CONDUCT OF PLANT CULTURES

Plants of the two strains were grown in water culture at different levels of nitrogen feeding, the nitrogen being supplied as sodium nitrate. Entire plants when 50 and 88 days old were harvested and subjected to chemical analysis.

Details of the procedure were as follows: From the 1935 crop, seeds from one ear of each strain, supplied by Doctor C. M. Woodworth, were used. They contained, respectively, 19.35 and 5.45% protein. The seeds were germinated in a sterilized rag doll and were transplanted when five days old to 1-gallon glazed stoneware jars containing nutrient solution. The seedlings were held in position by round covers of wood through which 1-inch holes had been drilled, the plants being held in place by small wads of non-absorbent cotton. The culture solution was replaced three times each week. Iron was given for a 24-hour period once a week by applying on Monday the complete solution minus phosphorus and magnesium, but containing iron as $FeCl_3$. On Tuesday and Friday the complete solution minus iron was applied. Only the nitrogen concentrations were varied. Four nitrogen levels were maintained, namely, 25, 50, 100, and 200 p.p.m.

The stock solutions were maintained in 11-liter bottles from which aliquots were taken and diluted with distilled water to give a culture solution of the composition shown in Table 1.

TABLE 1.—*Composition of culture solution.*

Element	Salt used	P.p.m. of element in final dilution
	Stock Bottle 1	
Ca	$CaCl_2 \cdot 2H_2O$	50.0
Mn	$MnCl_2 \cdot 4H_2O$	1.0
Cu	$CuCl_2 \cdot 2H_2O$	0.5
Zn	$ZnCl_2$	0.5
B	H_3BO_3	0.5
K	KCl	140.0
	Stock Bottle 2	
P	$NaH_2PO_4 \cdot H_2O$	28.0
Mg	$MgSO_4 \cdot 7H_2O$	48.0
	Stock Bottle 3	
Fe	$FeCl_3 \cdot 6H_2O$	20.0
	Stock Bottle 4	
NO_3	$NaNO_3$	Varied

The pH of the solution varied from 6.3 to 6.6 and was maintained at this level. Evidence of Clark and Shive (9, 10) and of Tiedjens (32) indicates that absorption and assimilation of nitrate ions are not greatly affected by the reaction of the culture solution.

Six seedlings were planted in each jar and the stand maintained by transplanting plants carried in extra jars during the first 10 days. Greenhouse lights were used on alternate nights. Plant growth was satisfactory and the plants appeared normal.

SAMPLING AND PREPARATION FOR ANALYSIS

Samples were taken 50 and 88 days after planting. It was desired to harvest the plants before the vegetative development was affected by fruiting. A few plants tasseled before the final sampling and they were discarded.

The preservation of plant tissue for subsequent analyses presented a problem for which no fully satisfactory working method was found. Experiments by Vickery, Pucher, and Clark (34), indicate that the use of hot water is of doubtful validity because of the possibility of hydrolysis of glutamine and consequent liberation of ammonia. The use of cold water did not give complete extraction and was not practicable because of its inability to prevent enzymatic action. Freezing of the tissue was eliminated because of lack of facilities. Link and Schulz (24) obtained decreases in amount of soluble nitrogen when corn leaves were dried at various temperatures. Low temperatures of 32° to 45° C allowed proteolytic decomposition to take place, but no effect of the various temperatures on the total nitrogen content of the tissue was observed.

Inasmuch as the various nitrogenous components of the corn plant were desired unchanged it was concluded that hot water extraction offered the best available possibility with the least error. The method finally used, which is given in the following paragraph, is founded upon work of Chibnall (7) who showed the possibility of essentially quantitative expression of the vacuole content of cells after cytolysis with ether. Grover and Chibnall (17) showed also that the likelihood of a significant production of ammonia from the enzymatic decomposition of amides during the brief process is remote.

The whole sample of six plants including roots and tops was harvested, weighed fresh, and finely cut and mixed in a Hobart salad cutter. A small portion was taken for moisture determination and the remainder immediately covered with ether. After 30 minutes at which time the tissue was entirely flaccid, 150 ml. of distilled water were added and the ether immediately evaporated on the steam bath. The water was stirred thoroughly with the plant tissue and decanted through a linen filter. Extraction and decantation with succeeding portions of hot distilled water were continued until no appreciable test for nitrates was obtained with diphenylamine.

The water extract was evaporated to somewhat less than 500 ml. on a steam bath (85° to 90° C) and then centrifuged in a whirling type centrifuge to remove chlorophyl, protein material coagulated by heating, and any solid material which may have passed through the linen filter. The water extract was made up to 500 ml., 1.0 ml. of chloroform added, and was then ready for chemical analyses. The solid portion remaining after centrifuging was combined with the extracted residue, dried in the electric oven at 100° C and set aside for chemical analysis. All chemical analyses given are on the water extract, plant residue, or the portion of original plant tissue used for moisture determination.

ANALYTICAL METHODS

It was considered desirable to determine not only the total nitrogen of the plant material, but also various inorganic and organic fractions which may represent stages in protein metabolism.

Total nitrogen.—Total nitrogen, including that from nitrates, was determined on a portion of the dried tissue by the official Kjeldahl method modified to include the nitrogen of nitrates (25).

Water-insoluble nitrogen.—Water-insoluble nitrogen was determined by the Kjeldahl-Gunning-Arnold method (25) on a portion of the plant residue after water extraction.

Water-soluble nitrogen.—Total nitrogen in the water extract was determined by the iron powder reduction method of Pucher, Leavenworth, and Vickery (30). Free ammonia, amide, and nitrate nitrogen (13) were successively determined on a second aliquot of the water extract, after which the residue from these determinations was subjected to nitrogen determination by the Kjeldahl-Gunning-Arnold method. The detailed procedures used in these determinations will be published elsewhere.

Total inorganic nitrogen.—Total inorganic nitrogen was calculated by combining the nitrate and anmmonium nitrogen.

Soluble organic nitrogen.—Soluble organic nitrogen was calculated as the difference between the total soluble nitrogen and total inorganic nitrogen and should consist chiefly of amino and amide nitrogen and secondary protein derivatives.

Residual water-soluble nitrogen.—No determinations of amino nitrogen were made. The residual nitrogen of the water extract, after removal of ammonia, amides, and nitrates is believed to consist chiefly of amino nitrogen and secondary protein derivatives. It was determined by the Kjeldahl-Gunning-Arnold method on the residue after the determination of ammonia, amide, and nitrate nitrogen, and it was also calculated by subtracting the sum of the above three fractions from the total nitrogen in the water extract as previously determined.

Moisture.—Moisture was determined by drying a portion of the original sample, after cutting and thoroughly mixing, at 100° to 101° C in an electric oven.

EXPERIMENTAL RESULTS

GROWTH OF PLANTS

During the first few weeks the plants of the high protein strain were noticeably darker green in color than those of the low protein strain, regardless of cultural conditions. This difference disappeared about 4 weeks after planting. All plants at the final sampling were dark green in color and normal in appearance. Green and dry weights of the 88-day-old plants are given in Table 2. The average dry weights of the low and high protein plants were 2.45 and 2.77 grams per plant, respectively. The high protein plants made greater growth at 100 and 200 p.p.m. of nitrogen than with 25 or 50 p.p.m. The low protein plants were approximately the same weight at 25, 50, and 100 p.p.m. of nitrogen and showed an increase at 200 p.p.m. Both strains at the 200 p.p.m. concentration were still growing actively when sampled.

TABLE 2.—*Average green and dry weights per plant when sampled (88 days).*

Nitrate nitrogen, p.p.m.	Green weight, grams*		Dry weight, grams*	
	Low protein	High protein	Low protein	High protein
25	26.7	23.1	2.32	2.02
50	24.8	25.8	2.19	2.27
100	25.2	36.7	2.23	3.13
200	34.2	42.9	3.08	3.76

*Per plant.

CHEMICAL COMPOSITION OF PLANTS

The following discussion is confined to the study of the 88-day-old plants. The results of the analyses of the younger plants showed similar trends. In discussing the analytical results the total nitrogen and the various groups of nitrogenous constituents will be considered separately. For convenience in studying the data, however, they are brought together in the same table. These values, expressed as percentage of the dry tissue and as milligrams of nitrogen per plant, are presented in Table 3.

Total nitrogen.—The two strains differed greatly in behavior as to nitrogen absorption at the different nitrogen-feeding levels. At both the lower levels, 25 and 50 p.p.m., the two strains were about equal in total nitrogen content, varying around 75 milligrams per plant (Table 3). At 100 p.p.m. the low protein strain remained unchanged while the high protein strain doubled its nitrogen content, containing 159 milligrams per plant. With a still further increase to 200 p.p.m. in the cultures, the high protein strain failed to absorb appreciably more nitrogen, but the low protein strain made a significant gain to 114 milligrams per plant. These differences are much greater than are accounted for by the increased plant growth as is shown by the percentage data in Table 3.

Water-insoluble nitrogen.—Water-insoluble nitrogen made up 50% or more of the total nitrogen present, except at 100 and 200 p.p.m. in the high protein strain. The higher proportions occurred at the

TABLE 3.—*Total nitrogen and nitrogen fractions in plant tissue, plants 88 days old.*

Kind of nitrogen	In low protein corn* grown with nitrate nitrogen at								In high protein corn* grown with nitrate nitrogen at							
	25 p.p.m.		50 p.p.m.		100 p.p.m.		200 p.p.m.		25 p.p.m.		50 p.p.m.		100 p.p.m.		200 p.p.m.	
	Mg.	%	Mg.	%	Mg.	%	Mg.	%	Mg.	%	Mg.	%	Mg.	%	Mg.	%
Total nitrogen	76 7	3.31	71.6	3.27	77.3	3.47	114.5	3.72	74.3	3.68	83.7	3.69	159.5	5.10	163.9	4.36
Water-insoluble (protein) nitrogen	47.5	2.05	40.3	1.84	43.3	1.94	57.1	1.85	44.2	2.19	48.2	2.12	77.4	2.47	77.9	2.07
Total water-soluble nitrogen	30.6	1.32	30.2	1.38	35.3	1.58	57.4	1.86	31.1	1.54	34.6	1.52	82.9	2.65	85.9	2.28
Ammonia nitrogen	2.0	0.08	1.6	0.07	1.8	0.08	3.0	0.09	1.9	0.09	2.3	0.10	6.5	0.21	4.7	0.12
Amide nitrogen	2.5	0.11	2.2	0.10	2.1	0.09	3.2	0.10	3.3	0.16	3.6	0.16	7.2	0.23	6.6	0.18
Nitrate nitrogen	10.9	0.47	9.5	0.43	12.2	0.55	24.8	0.81	8.7	0.43	8.1	0.39	25.7	0.82	30.6	0.81
Total inorganic nitrogen	12.9	0.56	11.1	0.51	14.0	0.63	27.8	0.90	10.6	0.52	10.4	0.46	32.2	1.03	35.3	0.94
Soluble organic nitrogen	17.7	0.76	19.1	0.87	21.3	0.96	29.6	0.96	20.5	1.02	24.2	1.07	50.7	1.62	50.6	1.35
Amino nitrogen	15.4	0.66	15.9	0.73	19.2	0.86	24.4	0.79	16.8	0.83	20.3	0.89	41.0	1.31	43.4	1.15

*Per plant.

lower nitrogen-feeding levels (Fig. 2). This indicates an increasingly complete conversion into proteins with restriction of the available supply. Water-insoluble nitrogen followed exactly the same trend as total nitrogen. That is, the high protein strain made a large gain at 100 p.p.m., while the low protein strain showed no change until the 200 p.p.m. feeding level was reached.

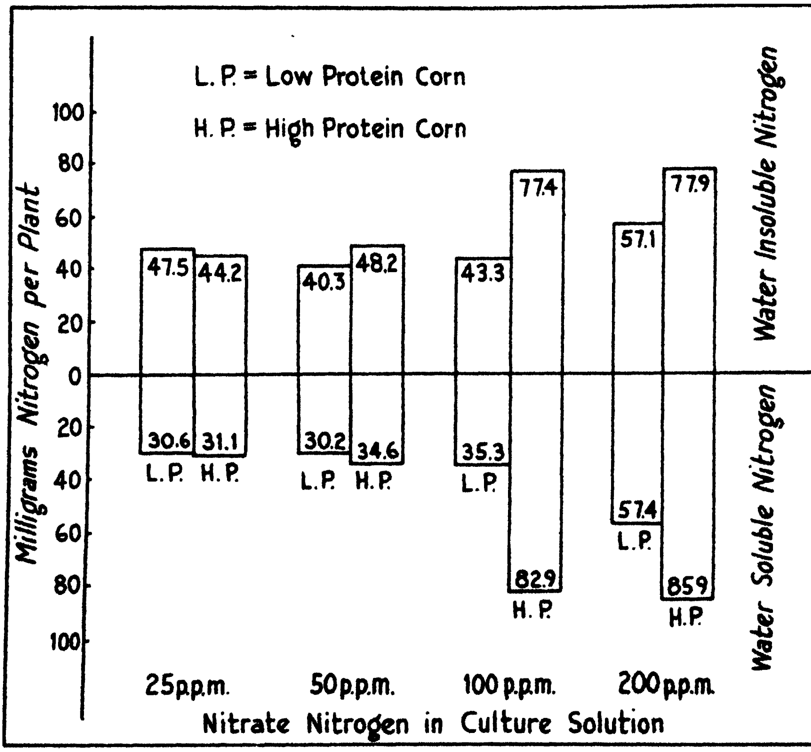

FIG. 2.—Total nitrogen (milligrams per plant) and its separation into water-insoluble and water-soluble portions.

Water-soluble nitrogen.—Plant analyses revealed a similar situation in the total water-soluble nitrogen as was shown for the water-insoluble portion. The high protein strain made its largest gain at 100 p.p.m. of nitrate nitrogen, while the low protein strain gained in this constituent only when the nitrogen fed was further increased to 200 p.p.m. (Figs. 2 and 3). But upon breaking this fraction down it was found that not all the water-soluble constituents follow this trend. The components of the water-soluble fraction are shown in Fig. 3.

Nitrate nitrogen.—Nitrates were accumulated in comparatively large amounts at the two higher feeding levels in the high protein plants, but only at the highest (200 p.p.m.) level in the low protein plants. At 200 p.p.m. the low protein plants had the same nitrate content as had the high protein plants at 100 p.p.m. (Fig. 3).

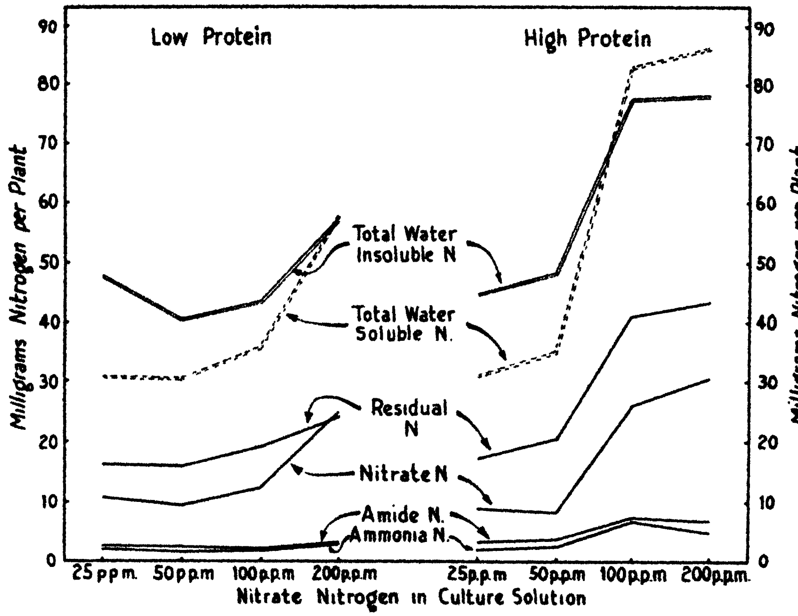

FIG. 3.—Nitrogen fractions in plant tissue, plants 88 days old.

Ammonia nitrogen.—The low concentrations of ammonia nitrogen throughout, support the commonly accepted view that ammonia is a transition compound which is converted to other forms almost as fast as it is produced.

Amide nitrogen.—Amides, like ammonia, appear to be transient forms but accumulate in slightly larger amounts than does ammonia in the high protein strain.

Residual water-soluble nitrogen.—This fraction, embracing as it does the immediate precursors of the proteins, is a good index of relative synthesizing ability of the plants. The superiority of the high protein strain is shown by its high accumulation of these materials at the two higher feeding levels *in addition* to its production of excessive amounts of the proteins themselves.

DISCUSSION

Throughout the 40 years of the development of these two strains of corn they were grown on productive soil of moderately high, but not excessive, nitrate-producing capacity. It is a striking fact that in these cultures the widest difference in nitrogen absorption and assimilation also occurred in the cultures of moderate, but not excessive, nitrate-supplying capacity (100 p.p.m.). Increasing or decreasing the nitrogen supplied has been shown to narrow the difference in total and protein nitrogen as well as in other nitrogen fractions during vegetative growth. Whether or not the protein in the grain at maturity will be similarly equalized by very high or very low nitrogen feeding is still to be determined.

The differential absorption of nitrates suggests the possibility of a "resistance mechanism" to absorption. This resistance is lower in the high protein strain, being overcome by an external concentration of 100 p.p.m., of nitrate at which concentration abundant intake occurs. But in the low protein strain the resistance is much greater, being above 100 p.p.m., since it was only in the 200-p.p.m., culture that nitrate absorption occurred in more than minimal quantity (Fig. 3).

NITROGEN ASSIMILATION

The toxicity of the ammonia ion to most plants is fairly well established and a detoxifying agent is probably present. Prianischnikov (29) considers the formation of asparagine to be for the purpose of detoxicating ammonia in plants and to be comparable to the formation of urea in animals. With increased amounts of ammonia in this study there was a parallel increase in amount of amide nitrogen (Fig. 3). Further evidence of ammonia detoxication by amides was afforded by a concurrent series of ammonia cultures, in which nitrogen was supplied as $(NH_4)_2SO_4$ at 25, 50, and 75 p.p.m. In no case did the ammonia nitrogen in the tissues rise as high as the maximum in the nitrate cultures, although the amide nitrogen was consistently more than twice as high as in the nitrate cultures. Evidence obtained in the ammonia cultures indicated that significant amounts of ammonium ion were absorbed and utilized in growth. The 75-p.p.m., cultures were started at 100 p.p.m., of ammonia nitrogen, but severe toxic symptoms necessitated early reduction of the concentration to 75 p.p.m.

Returning now to the nitrate cultures, the high protein plants at 100 and 200 p.p.m. contained more ammonia and amide nitrogen than the corresponding low protein plants. The high ammonia and amide nitrogen in these plants suggests that they have more adequate facilities (enzymatic activity) for reducing nitrates to ammonia than do the low protein plants. Then, so long as the nitrate supply is limited, both strains use up the ammonia and amides for forming other nitrogenous compounds as fast as they can be produced from the low nitrate supply. But at high nitrate feeding levels reductase activity goes so rapidly in the high protein plants that the ammonia and amides cannot be used up as fast as they are formed and they accumulate. The low protein plants, on the other hand, with less reducing capacity, can only produce ammonia and amides about as fast as these compounds are transformed into protein, so that no accumulation occurs. One might argue, if this is true, that nitrates should then accumulate in the low protein plants instead of ammonia and amides, and that is just what happened as soon as the threshold resistance to nitrate absorption was exceeded.

Under the conditions of greatest differentiation in nitrogen composition between the two strains of corn, namely, when grown with an adequate but not excessive nitrate supply, the high protein strain, as compared to the low protein strain, has been found to contain significantly larger quantities of all the nitrogenous constituents studied These substances include, in addition to unassimilated nitrates, insoluble proteins undoubtedly fixed as protoplasmic material and transi-

tion products. Such a finding points to a generally more vigorous metabolic activity in the high protein strain. Whether grain formation in the reproductive stage takes place exclusively at the expense of the soluble and quickly mobile nitrogenous constituents accumulated in the vegetative tissue, or whether, on the other hand, the more complex, insoluble protein in the protoplasm of vegetative cells is rehydrolized and moved into the ear to contribute to grain formation is debatable. The final answer to this question will require further comparative study of the two strains at stages up to maturity.

SIGNIFICANCE OF RESULTS

Evidence has been obtained which indicates that inheritable characteristics developed under a given nutritional environment do not necessarily find expression, at least to the same extent quantitatively, when placed under different nutritional conditions. This is not new. Five years ago one of the authors, with others (12), demonstrated a similar behavior of two single-cross corn hybrids with respect to phosphorus. On a phosphated soil one hybrid grew more rapidly, matured earlier, and yielded more corn than the other, but on a phosphorus-deficient soil no differences between the two were observable. Chemical studies of the plants explained the differences as due to different intensities of metabolic activity. Furthermore, it is commonly observed that corn varieties accommodated to soils that are poor to fair, do not on more fertile soils, compare favorably with varieties or hybrids developed on soils of high productivity.

In view of these observations it appears that it should be possible by undertaking corn breeding investigations on soils, built up to the highest possible state of fertility, to develop strains which would make 100-bushel corn yields more nearly the rule than the exception. It is probably true that such strains would not do so well on our ordinary corn-belt soils as some of the better hybrids now in existence. Nevertheless, farmers have frequently been disappointed by their corn yields on soils which are unusually high in fertility. The increasing frequency of these occurrences indicates that such "super-strains" would not be entirely without usefulness in practical agriculture.

SUMMARY

Two strains of white dent corn which differ widely in the protein content of the mature grain when grown on relatively productive soils and which had been selected through 40 generations for high and low protein content were used for this investigation. Plants of both strains were grown in water cultures containing, respectively, 25, 50, 100, and 200 p.p.m., of nitrate nitrogen. Plant yields, total nitrogen content, and nitrogen distribution among various fractions were determined during vegetative growth.

Green and dry weights of plants increased somewhat with increasing nitrate supply.

At the two lower nitrate-feeding levels both strains contained around 75 mgm. of total nitrogen per plant. At 100 p.p.m. the low protein strain still contained the same amount, but the amount was

more than doubled in the high protein strain. With a further increase of nitrogen in the culture solution to 200 p.p.m., the low protein corn gained in nitrogen content, approaching the high protein strain, which failed to make further appreciable gain.

Of the nitrogen fractions the water-insoluble and residual water-soluble nitrogen as well as nitrates reflected the same situation as was shown for total nitrogen, thus indicating a distinct superiority of the high protein corn in assimilation as well as absorption at the 100 p.p.m., nitrogen feeding level. Its superiority tended to disappear at lower or higher feeding levels.

Ammonia and amides were low in amount in the plant tissue and varied only slightly at the different feeding levels, indicating that they are intermediate stages in protein synthesis which are used up about as fast as they are formed. Some evidence is shown that the formation of amides serves to prevent toxic concentrations of ammonia in the plant tissues.

The significance of the results is discussed with particular reference to the possibility of combining soil improvement and corn breeding studies in order to secure the benefit of the maximum combined producing capacity of both crop and soil.

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MANAGEMENT OF KANSAS BLUESTEM PASTURES[1]

A. E. Aldous[2]

THE Kansas bluestem pasture region has an area of approximately 5 million acres. It occupies a belt varying in width from 25 to 100 miles extending north and south across the western side of the eastern third of the state. Much of this land is too broken or the soil too shallow or cherty to make its cultivation possible or advisable. The soils, however, are well adapted to the growing of the bluestem grasses. The normal annual precipitation in the region ranges from about 30 inches at the north end to approximately 36 inches on the southern end.

The vegetation was originally prairie grasses, big and little bluestems (*Andropogon furcatus* and *A. scoparius*) being the dominant species. The little bluestem was the principal species on ridge tops and the big bluestem was the dominant grass in the better land, the valleys, and on the slopes. Other grasses of secondary importance consisted of side oat grama (*Bouteloua curtipendula*), switch grass (*Panicum virgatum*), Indian grass (*Sorghastrum nutans*), and prairie June grass (*Koeleria cristata*). Kentucky bluegrass (*Poa pratense*) was increasing very rapidly until 1934, but the abnormal dry hot conditions that prevailed during that and the two succeeding summers have eliminated it. Blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*) have invaded many of the pastures, occupying the ridge tops and other areas having shallow soils. There has also been a great increase during the dry years of weedy annual grasses, mainly *Hordeum pusillum* and the annual species of Bromus. Other grasses of secondary importance include *Schedonnardus paniculatus*, *Sporobolus cryptandrus*, *Chloris verticillata*, *Eragrostis pectinacea*, and *Sporobolus asper*.

A large percentage of the stock grazed in the bluestem region are shipped in from Texas, New Mexico, and western Kansas The grazing season usually opens the latter part of April on commercially leased pastures and extends until about the middle of October. The season may be extended to the latter part of November during favorable years.

GRAZING CAPACITY

There has been a steady decline in the grazing capacity of the bluestem pastures. Prior to 1900 most of the pastures were stocked at the rate of 2 acres for a cow or mature steer. The average has been gradually decreased until in 1933, or before the present dry cycle started, the best pastures were carrying one mature animal to 4 acres, while the average for the bluestem region as a whole was 5 acres per head for the summer grazing period. During the past two years the average grazing capacity has been 7 acres for a cow or a 3-year-old steer.

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The declining grazing value of the bluestem pastures led the Experiment Station of Kansas State College to initiate experiments in 1916 to obtain information on methods of utilization that would maintain the productivity of this large area of pasture land. The experiments were started on 1,400 acres of typical Flint Hill or bluestem type of pasture land located in Pottawatomie County about 10 miles north of Manhattan. The experiments were conducted in cooperation with Mr. Dan D. Casement who supplied the land and cattle. The Experiment Station built the fences, installed scales for obtaining the weights of the stock, and located and charted plots and quadrats for studying the succession of the vegetation.

In the original experiment a deferred and rotation system of grazing was compared with season-long grazing. A deferred and rotation system of grazing was practiced in three pastures, each of these pastures being protected from grazing once every three years until seed matured which in an average year was approximately September 15. This was changed after four years to a deferred system of grazing. The data obtained indicated that the bluestem grasses could maintain a normal ground cover vegetatively if properly utilized and that the production of seed was not necessary for maintaining a normal stand of grass. It was determined also that much of the grazing value of the bluestem grasses was lost after they matured and became less leafy. This was reflected in the gains made by the livestock.

The grazing experiments were discontinued at the close of the season of 1922 and were resumed the summer of 1926. Experimental results are therefore not available for the years 1923 to 1926, inclusive.

Table 1 contains the carrying capacity data for the 17 years that the experiments have been conducted. These grazing capacity data are calculated on the basis of a mature animal, either steer or cow, for a 180-day grazing period.

TABLE 1.—*Effect of method of grazing on the carrying capacity of bluestem pastures, acres per mature animal.*

Year	1916	1917	1918	1919	1920	1921	1922	1927	1928
Season-long grazing...	4.79	5.24	4.64	4.73	3.67	4.10	4.55	4.59	4.28
Deferred grazing......	4.28	3.68	5.95	4.47	2.58	2.98	3.24	2.55	3.70
Year	**1929**	**1930**	**1931**	**1932**	**1933**	**1934**	**1935**	**1936**	**Mean**
Season-long grazing....	5.99	5.44	5.66	4.84	4.84	4.97	8.32	5.16	5.04
Deferred grazing.......	3.59	2.50	2.27	3.83	3.35	2.74	4.28	3.57	3.50

As previously stated, the stock were not turned in the deferred pasture until September during the first four years that the experiments were conducted. The grass, mature and stemmy at this stage of growth and rather low in palatability, was only approximately 50% utilized. Starting in 1920, the stock were turned in the deferred pasture about June 15 or when the available data indicated that the grass had made enough growth to maintain its vigor and while it was still leafy and palatable. The grazing capacity data were calculated for two pastures that were grazed the season long and for one pasture

when the grazing was deferred. One of the pastures grazed the season long had an area of 1,058 acres while the other contained 117 acres. The deferred pasture contained 111 acres. The grazing capacity of the large pasture was about 15% lower than that of the smaller pasture. This difference was due mainly to lack of water in one part of the large pasture which prevented the utilization of the forage on approximately 150 acres during a dry season.

It was found in averaging the number of pasture days obtained from the two pastures grazed the season long and comparing the result with the pasture grazed by the deferred system that approximately 30% increase in carrying capacity was obtained by the use of the deferred method of grazing. Comparing the results obtained from the two pastures of similar size, the deferred pasture carried 24% more stock than the pasture grazed the season long.

The practicability of applying a deferred system of grazing will depend upon the availability of water throughout the pasture or the cost of water development in any unit. The cost of fencing is also an important factor to be considered as is the topography and the kind and uniformity of the forage.

EFFECT OF METHOD OF GRAZING ON GAINS OF LIVESTOCK

Beginning with 1927, weights were taken of the livestock in the different pastures. The weights were taken at the time the stock were placed in the pastures and when they were removed. They were also weighed when they were placed in the corrals for vaccinating, marking, etc., which was about once each month. The weights were usually taken in the morning. Table 2 records the average gain per animal unit per day and Table 3 records the pounds increase or decrease per acre made by the livestock for the entire season under the two methods of grazing management.

TABLE 2.—*Gains of livestock, pounds per animal unit per day, under season-long and deferred systems of grazing, 1927 to 1936, inclusive.*

	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	Mean
Season-long grazing	1.33	1.25	1.50	1.28	1.76	1.06	1.12	0.19	2.05	1.27	1.28
Deferred grazing	1.34	2.17	1.77	0.80	1.95	0.85	1.31	0.09	1.31	1.32	1.29

TABLE 3.—*Gains made by livestock, pounds per acre, in pastures grazed season-long and where grazing was deferred, for the 10-year period 1927 to 1936, inclusive.*

	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	Mean
Season-long grazing	93	70	43	42	61.5	41	58	−83	46	44	49.8
Deferred grazing	92	86	88	57	109	46	71	6.4	55	53	66.3

The gain per animal unit per day was slightly higher for the deferred system of grazing. The difference of 0.01 pound per day is not enough to be significant. The gain per acre averaged 16.5 pounds or 33% greater for the deferred method of grazing.

The pastures were grazed by Hereford cows and calves. The calves were dropped during April and May. In the grazing capacity calculations, four April or May calves grazed until the close of the season were estimated as consuming as much forage as one cow. The increase in weight made by the livestock has been greatly reduced since 1933 owing to the abnormally dry conditions that have prevailed. The summer of 1934 was especially severe, the forage production was short and little if any increase in weight was made. The pastures were stocked with the average number of animals that they carried in previous years. This was about double the number that should have been placed on them. The number was greatly reduced in 1935 to allow the pastures to become re-established.

EFFECTS OF METHOD OF GRAZING ON DENSITY AND SUCCESSION OF VEGETATION

In the early spring of 1927, 25 permanent meter-square quadrats were established in pasture No. 1 or the large pasture grazed the season long, 14 in pasture No. 2 utilized by the deferred system of grazing, and 15 in pasture No. 3 grazed the season long. Four quadrats were also established in an enclosed area protected from grazing. These were established to study plant succession under natural conditions. All these quadrats were charted each June because the bluestem type of vegetation is more vigorous and uniform at this time. The average composition of each quadrat in the series for the years 1927, 1930, 1935, and 1936 is recorded in the following tables. In charting the quadrats, the position and area of each plant or group of plants was recorded on coordinate paper 1 decimeter square, or a scale of 1:10. The data for the grasses represents the average number of square centimeters per square meter on which the vegetation completely covered the ground. The data for the weeds or forbs are recorded in average number of plants per square meter. Only the more important species are listed individually in Table 4.

An analysis of these data shows a decrease in the density of the vegetation from 1927 to 1936. The decrease was greatest in the charting made in 1935. This was due to the very dry, severe condition that prevailed in 1934 and the very close grazing to which all the pastures were subjected during that summer. As previously stated the drouth was most severe on bluegrass (*Poa pratense*), although there was more than a 50% decrease in the two species of Andropogon, the dominant and most valuable pasture grasses in the region. Little barley (*Hordeum pusillum*) made its appearance in sufficient abundance in 1935 to be recorded in practically all the quadrats. This resulted from the reduction of the density of the perennial grasses. The quadrat data show that among the desirable grasses side oat grama was injured least, having maintained a high percentage of its original stand through the drouth, and has made a more rapid come back since 1934.

TABLE 4.—*Average density of vegetation per square meter on charted quadrats.**

Year	Af	As	Sn	Pv	Bc	Bh	Sc	Bd	Pp	Kc	Hp	Other grasses	Total grasses	Carex	Weeds	Total
							Pasture No. 1									
1927......	343	367	8	7	403	68	34	4	495	7	—	127	1,863	78	96	2,037
1930.....	318	117	169	20	230	21	13	6	227	11	—	39	1,231	92	70	1,393
1935......	137	22	9	2	140	21	74	26	—	3	93	21	548	13	100	661
1936......	152	27	1	4	219	29	98	44	—	—	39	15	628	22	84	734
							Pasture No. 2									
1927....	457	316	10	—	221	13	4	—	790	—	—	12	1,823	45	97	1,965
1930......	442	216	188	30	307	7	3	20	379	18	—	13	1,623	78	94	1,795
1935......	222	147	11	—	189	16	1	1	—	14	13	11	614	33	95	742
1936....	240	155	2	8	203	2	43	2	—	1	14	15	686	15	60	760
							Pasture No. 3									
1927......	566	336	24	14	207	27	82	481	271	—	—	86	2,094	101	97	2,292
1930......	441	126	78	23	246	—	20	54	315	19	—	122	1,444	121	135	1,700
1935....	200	56	14	2	176	39	42	14	4	14	117	46	724	23	149	896
1936......	252	59	9	4	310	32	84	4	—	1	103	39	897	21	79	996
							Ungrazed									
1927......	633	183	76	—	60	—	—	—	10	—	—	2	964	179	164	1,307
1930......	538	201	105	—	52	—	—	—	108	—	—	18	1,022	296	57	1,348
1925......	529	166	38	—	33	—	—	—	23	—	—	19	808	164	34	1,006
1936......	548	316	39	—	102	—	—	—	16	—	—	—	1,021	250	40	1,311

*Af—*Andropogon furcatus*
As—*Andropogon scoparius*
Sn—*Sorghastrum nutans*
Pv—*Panicum virgatum*
Bc—*Bouteloua curtipendula*
Sc—*Sporobolus cryptandrus*

Bh—*Bouteloua hirsuta*
Bd—*Buchloe dactyloides*
Pp—*Poa pratensis*
Kc—*Koeleria cristata*
Hp—*Hordeum pusillum*

All three pastures show approximately the same successional trends, there being a decrease each year until the growing season of 1935. There were a larger number of plants of little barley in pasture No. 3 than in the other two pastures. The greater number largely accounts for the increased percentage of grasses in this pasture in June 1936 over pastures Nos. 1 and 2. Sand drop seed (*Sporobolus cryptandrus*) has increased in all pastures through the drouth. This is generally true in all pastures throughout the Flint Hill region. This grass is low in palatability but will hold the soil from eroding and is readily replaced by the more desirable grasses upon the return of more favorable growing conditions.

The ungrazed areas showed a more stabilized condition with little change even after 1934. There has not been any invasion on these plots of the weedy grasses such as *Sporobolus cryptandrus* or *Hordeum pusillum* or the short grasses (*Bouteloua gracilis* or *Buchloe dactyloides*). The quadrat data for the ungrazed plots show the density of the vegetation to be equally as high in 1936 as in 1930 when the highest density was recorded The density of the vegetation was much less for the ungrazed plots owing to the larger amount of big bluestem which makes a higher top growth. This tends to reduce tillering and spreading on the ground.

The maintenance of a somewhat normal stand of vegetation on the ungrazed plots suggests that the injury from the drouth came largely from high soil temperatures rather than lack of soil moisture. The moisture content of the ungrazed plots was no higher than the grazed, but the daily maximum temperatures of the soil at a depth of 1 inch was at least 4° F less on the plots protected from grazing. The close cropping of the grazed areas also weakened the plants making them more susceptible to injury.

NUTRIENT VALUE

Bluestem grasses are very palatable and nutritious in their leafy stages of growth. An indication of their nutrient value is shown in Table 5.

These data indicate that the ungrazed bluestem grasses are very nutritious and capable of producing good gains until early July. After this time they become less leafy, more stemmy, and are gradually reduced in nutritive content and palatability. The moderately grazed pasture will provide very good forage until its growth is checked by dry weather. Its value may increase in late summer and fall with reduced temperatures and normal rainfall. The quality of the bluestem grasses will be governed by the stage of maturity and their succulence. In an average year a moderately grazed bluestem pasture will provide good palatable nutritious forage through the growing season. The growing conditions will be an important factor in the quality of the forage.

An analysis of the calcium and phosphorous content of the bluestem grasses showed an adequate calcium content. They also contained enough phosphorus in the leafy stages of growth to meet the mineral requirements of livestock. The phosphorous content de-

TABLE 5.—*Protein and crude fiber content of bluestem grasses at different stages of growth from ungrazed and moderately grazed pastures.*

	May		June			July		August		September		October
	8	19	5	16	29	16	30	11	29	10	22	3
	Ungrazed											
Protein, %	15.80	13.20	8.99	7.82	6.26	6.13	5.45	5.36	5.48	4.65	3.76	3.46
Crude fiber, %	26.0	28.25	31.40	31.25	32.67	33.60	36.04	34.78	33.65	33.20	33.40	34.73
	Plucked from Moderately Grazed Pasture											
Protein, %	15.78	13.65	12.35	10.40	7.59	6.57	5.16	4.53	6.62	7.92	7.25	7.35
Crude fiber, %	25.92	26.13	25.99	28.95	29.22	28.94	28.93	29.23	28.31	30.10	30.22	28.44

creased as the grass matured. The calcium ranged from 0.550% in the immature stages of growth to 0.328% in the mature plants. The phosphorous content ranged from 0.300% in the grass during May to 0.100% in September when the grass was mature. Moderately grazed bluestem grass had a minimum phosphorous content of 0.198%.

In addition to the above, bluestem grasses are valuable pasture plants because they make a major portion of their growth during June and July, and if moisture is available, a substantial amount of forage will be produced during August. In contrast with this most of the "tame" perennial grasses are semi-dormant after their normal period for maturing seed or from July until late summer or early fall.

EFFECT OF CLIPPING ON FOOD RESERVES, YIELDS, AND SUCCESSION OF BLUESTEM GRASSES

Since it is impossible to measure accurately the effect of different grazing treatments on the growth and succession of vegetation, an effort was made to obtain these data through clipping the vegetation at different frequencies simulating, as nearly as possible, various intensities and methods of grazing. The plots were established in May 1927 in typical bluestem vegetation and the clipping was started immediately afterward.

Table 6 records the effect of the different frequencies of clipping bluestem grasses on the percentage of total starches and sugars in the roots, the yield per acre of top growth and roots, and the succession of big and little bluestem. The change in the density of big and little bluestem grasses, or succession, was recorded in square centimeters complete basal ground cover of vegetation per square meter for the years 1927 and 1933. All plots from which these data were obtained were clipped to a height of 1½ inches.

TABLE 6.—*Effect of clipping on the total percentage starches and sugars in roots, yield of forage and roots, and the change in the density of the vegetation from 1927 to 1933.*

	Un-clipped	Clipped every 14 days	Clipped every 21 days	Clipped every 14 days, July 1–Oct. 1
Starches and sugars, %	14.07	9.18	10.03	10.64
Yield of vegetation, lbs. green weight per acre	4,171	2,444	2,943	3,850
Dry weight of roots, lbs. per acre, top 7 inches of soil	6,703	2,705	4,233	4,928
Density of big bluestem, sq. cm. per meter 1927–33	750; 645	556; 47	629; 184	763; 246
Density of little bluestem, sq. cm. per meter, 1927–33	201; 274	338; 52	348; 92	146; 134

The total starches and sugars in the roots of the grasses, which represent the principal food reserve elements, were analyzed at the close of the 1928 grazing season. The sod was dug to a depth of 7 inches and the roots removed from the soil by washing. These data

represent the effect of clipping during two seasons. It will be noted that the total starch and sugars were very high in the unclipped grass. The amount was moderately high in the roots obtained from the plots protected until August then clipped at 2-week intervals until October or until little or no growth is made in the bluestem grasses. This indicates that the building up of the food reserves in the roots is mainly done during the beginning of the season. This agrees with grazing experiments which show that the greatest injury to bluestem grasses arises from close grazing at the beginning of the growing season and that the pastures are greatly improved by protection or lightly grazing during May and June. The plots clipped every 3 weeks, which represents rather close grazing, showed a materially reduced starch and sugar content in the roots, the amount in all probability being insufficient to promote the most vigorous growth. The plots clipped every 2 weeks, which represents very close grazing, was extremely low in food reserves. The bluestem grasses made little growth the second year on these plots and were being replaced by weedy species.

The yields of forage obtained from the clipped plots represent an average of seven years, 1927 to 1933, inclusive. They vary inversely with the frequency of clipping. The highest yield, or 4,171 pounds green weight, was obtained from the plots that were clipped at the end of the growing season. The lowest yield was obtained from the plot clipped every 2 weeks. Over 50% of the material harvested from this plot was annuals as was shown by the studies on succession. The plot clipped every 3 weeks had about one-third of its foliage during the last two years composed of annuals and weeds.

The data on the yield of roots was obtained by digging 2 square feet of sod on each plot to a depth of 7 inches. The yields represent an average of three years results, 1928 to 1930, inclusive. The yield of the roots is very closely correlated with the yield of the top growth. The yield of roots as well as the top growth decreased as the clipping treatments were extended from year to year. The root content of more closely clipped plots was composed of from 30 to 60% of annuals and weeds during the last year that the root data were obtained.

The data on the succession of the vegetation are recorded for big and little bluestem, which represented 75% of the vegetative composition at the time the first chartings were made. These data were not extended to 1934 owing to complications arising from the extreme drouth which effected all plots very severely. There was little decrease in the density of the unclipped plots. The other extreme developed in the plots clipped every 2 weeks, eliminating the two dominant grasses with the exception of scattered plants that were the remants of vigorous clumps. The plots clipped every 3 weeks throughout the year had retained approximately a fifth of a stand, but the plants were greatly reduced in vigor. The plots clipped every 2 weeks after August 1 had retained approximately a 40% stand.

DISCUSSION AND CONCLUSIONS

The Kansas bluestem region has been gradually decreasing in carrying capacity, the decrease being most pronounced after extreme-

ly dry seasons. To obtain information on methods of grazing management that could be used to maintain the grazing value of this large acreage of grazing land, the Kansas Agricultural Experiment Station initiated grazing experiments in 1916. The earlier experiments of deferring grazing until after seed was mature resulted in a great waste of forage owing to the grasses being tough and unpalatable after they have completed their growth. After four years, the grazing was deferred only until about June 15 when the forage was palatable and nutritious. This period of protection every two or three years was believed to be sufficient to maintain the normal stand and vigor of vegetation.

The results of the deferred system of grazing gave an increase of approximately 25% in carrying capacity and 33% increase in the gains in pounds of livestock per acre over that obtained in the pastures grazed the season long. The desirable forage species were maintained equally as well in the deferred as in the pasture grazed the season long.

The crude protein and the mineral content of the bluestem grasses are high enough in their leafy stages of growth to provide adequately for the nutritional requirements of the livestock as well as to provide satisfactory gains in weight. Clipping experiments showed the yield of the tops and roots to be inversely proportional to the frequency of clipping. The density of the desirable grasses and their food reserves were approximately in the same proportion.

The study indicates that a deferred system of grazing may be used to obtain the highest use of the bluestem pastures with the minimum amount of injury.

The application of this system requires the additional fencing or the use of tillable land to grow supplemental pasture crops to provide forage for livestock during the early part of the grazing season when the grazing is deferred. The latter is not practical in a major part of the area because of the very small percentage of tillable land available for this purpose.

THE RELATION OF FERTILIZERS TO THE COTTON PLANT PRODUCED IN THE BLACKLAND PRAIRIE SECTION OF TEXAS[1]

H. V. JORDAN, J. H. HUNTER, AND J. E. ADAMS[2]

CORRELATED field and laboratory studies of the relation of fertilizers, tillage, and crop residues to the yield and maturity of cotton and the incidence of cotton root-rot, have been made by the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. A report of some of the early work (4)[3] gave data which showed that an evasion of losses in yields due to the soil-borne fungus *Phymatotrichum omnivorum* (Shear) Duggar was accomplished to a degree by treatments which hastened the development of the plant. A reduction in the incidence of the disease was indicated for practices which tended to produce highly vegetative growth.

Susceptibility to root-rot becomes apparent in the field when the cotton plant has approximately six true leaves and is entering the fruiting stage. Planting after the normal date has been found, generally, to retard the initial appearance of the disease and to reduce losses (2, 5, 7). It is recognized that rapid early development and the production and retention of squares at the beginning of the season are factors in the earliness of the cotton crop (1, 3, 8). A prolongation of the period of rapid fruiting by nitrogen fertilizers is indicated by certain studies (8).

This report presents a limited study of the effect of fertilizers on the numbers of squares and bolls and on the heights of plants, using these as indices of development. The relation of these to the incidence of root-rot is discussed. A more complete and detailed morphological study of the relation of fertilizers to plant development is under way in cooperation with the Division of Cotton and Other Fiber Crops and Diseases, using an area uninfested by the disease.

PLAN OF EXPERIMENT

The use of the Latin square arrangement of plats was begun in 1935 to test further a number of fertilizers found by the triangle method of study (6) to be most outstanding for investigation on the Houston and Wilson soils. Two such experiments were conducted on Wilson clay loam in 1935; one was in Hunt County, on the farm of Richard Craig, near Campbell, Texas, and the other was near Elgin, in Travis County, on the farm of Emil Kruger. The experiment on the latter farm was repeated in 1936, and a new trial was begun near Caddo Mills, in Hunt County, on the farm of H. G. Williams. One such experiment was con-

[1]Contribution from the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 16, 1937.

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[3]Figures in parenthesis refer to "Literature Cited", p. 261.

ducted on Houston black clay in 1936 near Pflugerville, in Travis County, on the farm of Alfred Fuchs.

Fertilizers in each of the experiments included an 0–15–0, 3–9–3, 9–3–3, and 15–0–0 analysis[4], and unfertilized check plats were included. Percentages dead cotton for all plats were assembled periodically in each experiment. Plant data were obtained in two experiments on the Wilson soil, namely, those on the clay loam in 1935 and on the fine sandy loam in 1936. Similar data were obtained from a single experiment on Houston black clay in 1936. All root-rot data are amenable to statistical analysis, but only in 1936 were plant data so assembled.[5]

The data for the Houston black clay soil, and those of the Wilson series which are lighter in texture, are treated separately due to an inherent difference in their response to fertilizers.

DATA FROM THE WILSON SOILS

In following the extent of the attack on plants by root-rot, it is generally more convenient to measure the footage of dead cotton than that of green cotton. An increase in the percentage of dead cotton, as the season advances, is accompanied by a like decrease in green cotton. Differences quoted in the analysis of variance necessarily represent either dead or green cotton.

Periodic records of the amounts of dead cotton for the several plats for the four experiments on the Wilson soil are presented in Table 1. The value given for a particular treatment on a given date is an average of the individual values of five or six replications. Table 2 gives the results of the analysis of variance of the data given in Table 1.

The highly significant variance between means of dates is a reflection of the progressive increase or decrease in the percentage of dead or green cotton, respectively, with the advance of season. The variance between means of treatments is also highly significant, and fertilizers have had a valid effect on the prevalence of dead cotton as shown by a comparison of fertilized and non-fertilized plats.

The all-phosphate fertilizer, 0–15–0, increased the amount of dead cotton over that on non-fertilized check plats, the difference being statistically significant. Examination of the records obtained with the 3–9–3 fertilizer on individual dates shows that in some instances this fertilizer increased mortality significantly, while in some instances there were significant reductions. Reductions occurred particularly in the case of the experiment in Hunt County in 1936. The 3–9–3 fertilizer may function either to increase or reduce root-rot. The dual behavior of this analysis is not fully understood, but it is thought to depend on seasonal conditions, rates of application, and other factors. Both high-nitrogen fertilizers caused highly significant reductions in dead cotton as compared with unfertilized check plats.

Plant and yield data from studies on Wilson clay loam in 1935 are presented in Table 3. Although the plant records were secured at

[4]The formulas indicate N–P_2O_5–K_2O. The nitrogen was derived in equal proportions from sulfate of ammonia and nitrate of soda. Phosphoric acid was from superphosphate and potash from sulfate of potash. The rate of application was 900 pounds per acre.

[5]Acknowledgment is made to N. E. Rigler, D. R. Ergle, Prinston Jenkins, and H. A. Nelson for help at various times in collecting the data.

TABLE 1.—*Percentage dead cotton at successive dates in four fertilizer experiments on light-textured Wilson soils, 1935–1936.*

Plat treatment	1935											
	Wilson clay loam, Hunt County						Wilson clay loam, Travis County					
	July 18	July 31	Aug. 15	Aug. 28	Sept. 30	Oct. 17	June 21	July 5	July 19	Aug. 2	Aug. 16	Oct. 4
0–15–0	1.0	7.1	13.8	22.8	46.6	70.0	0.4	1.9	7.7	20.2	32.0	65.6
3–9–3	1.3	9.7	17.1	26.3	43.6	55.3	0.4	1.7	7.4	21.8	35.8	68.1
9–3–3	0.6	1.5	5.1	8.1	23.7	34.7	0.1	1.6	5.6	13.4	23.1	58.1
15–0–0	0.5	3.5	6.3	12.9	26.4	43.3	0.1	1.2	4.0	12.0	20.6	50.3
Check	2.0	8.1	16.7	27.4	52.6	70.9	0.2	0.9	3.7	13.1	23.5	57.0
Mean	1.1	6.0	11.8	19.5	38.6	54.8	0.2	1.5	5.7	16.1	27.0	59.8

Plat treatment	1936								Mean for the 2 years
	Wilson clay loam, Travis County				Wilson fine sandy loam, Hunt County				
	June 19	July 6	July 20	Aug. 3	July 14	July 28	Aug. 12	Oct. 7	
0–15–0	3.7	17.1	45.9	74.3	4.6	15.0	25.3	22.0	24.9
3–9–3	2.7	13.4	37.4	72.6	1.5	5.4	6.8	7.1	21.8
9–3–3	1.2	9.2	29.8	61.7	0.1	1.0	1.3	1.5	14.1
15–0–0	0.4	4.7	17.8	46.2	0.2	0.6	1.9	2.1	12.8
Check	2.4	10.1	27.6	59.5	2.4	9.3	16.5	13.7	20.9
Mean	2.1	10.9	31.7	62.9	1.8	6.3	10.4	9.3	

TABLE 2.—*Analysis of variance in percentages of dead cotton as affected by fertilizers in four experiments on Wilson soils, 1935–36.*

Source of variance	Degrees of freedom	Sum of squares	Mean square	F
Between means of dates	19	39,257.41	2,066.18	65.6*
Between means of treatments	4	2,174.09	543.52	17.3*
Error	76	2,393.65	31.5	—
Total	99	43,825.15		

*Exceeds the 1% point.

Plat treatment	Average % dead cotton	Increase or decrease due to treatment
0–15–0	24.9	4.0
3–9–3	21.8	0.9
9–3–3	14.1	–6.8
15–0–0	12.8	–8.1
Check	20.9	

Minimum mean difference for significance (P = 0.05) 3.5
Minimum mean difference for significance (P = 0.01) 4.7

approximately 1-week intervals, only averages for an early vegetative and fruiting period and a later period of boll development are given. An analysis of variance was not made.

During the early period height and number of squares were increased by all fertilizers, while increases in numbers of nodes and bolls were obtained with phosphate alone and with the complete fertilizers. The least effect, where obtained, was from the all-nitrogen (15–0–0) fertilizer.

Height and numbers of squares and bolls were also greater during the late period for all fertilizer treatments. Height and number of bolls were affected most by the complete fertilizers with little difference between the two. Only small differences in the average numbers of nodes were apparent among treatments. While the 15–0–0 fertilizer produced the minimum effect on height, nodes, and bolls during both periods, it gave the greatest average number of squares during the late period at each date of record.

Increases in yield from these fertilizers ranged from 88 to 356 pounds of seed cotton per acre. A significant acceleration of maturity, as shown by increased amounts at first picking, was obtained with each fertilizer except the 15–0–0.

These plant and yield data indicate that the 0–15–0, 3–9–3, and 9–3–3 fertilizers accelerated development, while nitrogen alone did not. There was a tendency, however, for the 15–0–0 to prolong the fruiting stage as shown by the greater number of squares during the late period.

Plant data obtained on the Wilson soils in 1936 are given in Table 4. These were treated by analysis of variance for each plant character for the several dates of observation. Significant differences due to some treatments are indicated.

Accelerated development, as shown by a predominance of signifi-

TABLE 3.—*Plant and yield data from an experiment on Wilson clay loam, Travis County, 1935.*

Fertilizer Treatment	Early period, June 11 to July 9				Late period, July 16 to Aug. 6				Acre yield of seed cotton, lbs.	
	Height of plant, inches	Number of nodes	Number of squares	Number of bolls	Height of plant, inches	Number of nodes	Number of squares	Number of bolls	Total	First picking
0-15-0	16.7	14.4	6.9	0.5	28.1	22.1	5.0	5.0	485*	319
3-9-3	20.4	15.5	10.4	1.4	30.5	21.1	5.2	7.5	665*	492
9-3-3	19.1	15.2	8.9	0.7	30.2	21.3	5.4	7.8	740*	514
15-0-0	14.8	13.9	6.3	0.3	26.0	21.1	11.7	5.0	472†	257
Check	14.3	13.8	5.1	0.3	22.5	21.8	4.5	4.1	384	208

*Yields are significantly larger than those of check plats ($P = 0.01$)
†Yields are significantly larger than those of check plats ($P = 0.05$)

cant increases in height and in numbers of bolls and squares at the several dates of record, is indicated for the 0–15–0, 3–9–3, and 9–3–3 fertilizers. Although plants grown on the 15–0–0 plats differed significantly from those on the unfertilized checks in only one instance, there is a tendency for a reduction in height and of numbers of squares and bolls recorded at the earlier dates.

TABLE 4.—*Plant and yield data from an experiment on Wilson fine sandy loam, Hunt County, 1936.*

Date	Plant character	Plat treatment				
		0–15–0	3–9–3	9–3–3	15–0–0	Check
June 16	Height, inches	10.33*	10.54*	8.33*	5.85	6.66
	Number of squares	2.15*	2.65*	1.71	0.80	1.12
June 23	Height, inches	10.97*	11.65*	9.93*	6.89	7.23
	Number of squares	2.80	3.60*	2.67	1.45	1.82
June 30	Height, inches	12.53*	13.13*	11.90*	8.72	8.80
	Number of squares	2.30*	2.15*	2.27*	1.25	1.12
	Number of bolls	0.50*	0.31	0.43*	0.10	0.13
July 13	Height, inches	15.77*	17.35*	17.02*	12.69	12.70
	Number of squares	1.17*	1.28*	1.62*	0.77	0.58
	Number of bolls	1.45*	1.55*	1.43*	0.50	0.67
July 27	Height, inches	17.27*	17.77*	18.37*	15.91*	15.03
	Number of squares	1.22	0.98	1.17	1.87	1.53
	Number of bolls	2.24*	1.89*	1.76*	0.83	0.64
August 11	Height, inches	17.87*	18.12*	18.47*	15.25	14.66
	Number of bolls	2.00	2.33*	1.92	1.55	1.42
Total yield of seed cotton per acre, lbs		210*	258*	202*	71	95
Bolls open August 13, %† . . .		52.1*	63.9*	48.8*	26.7	32.1

*Significantly greater than corresponding character on check plats.
†Only one picking made, counts of open bolls are offered in lieu of amounts at first picking.

If the 15–0–0 plat is used for reference rather than the unfertilized check, it is of interest to note that, through June, cotton on the 0–15–0, 3–9–3, and 9–3–3 plats had significantly more squares than plants from the 15–0–0 plats. On July 13, only the complete fertilizers maintained this same relative position, while on July 27, which was the final record date, plants on the 15–0–0 plats had significantly more squares than those on plats fertilized with phosphate alone or complete ratios. Thus, a trend towards prolongation of the fruiting period by the 15–0–0 fertilizer, is shown by comparison with other fertilizer treatments, although differences are not significant when comparison is made with unfertilized checks.

The crop was virtually a failure on the unfertilized and 15–0–0 plats, due principally to drouth. The 0–15–0, 3–9–3, and 9–3–3 fertilizers, however, increased yields and hastened the opening of bolls by margins which were significant in each case. The 15–0–0 fertilizer was not effective in either of these respects.

RESULTS ON HOUSTON BLACK CLAY

Concurrent studies of the effect of fertilizers on root-rot and plant character on Houston black clay are so far limited to a single experiment in 1936. Accordingly the data are not presented in detail.

Records of the occurrence of root-rot on the various plats were obtained on five successive dates from June 24 to October 2. Plats fertilized with the 0–15–0 fertilizer had higher percentages of dead cotton than the unfertilized check plats on the first two dates of record, namely, June 24 and July 8, the differences in each case being highly significant. The 3–9–3 fertilizer caused a significant increase in the percentage of dead plants on June 24. The high-nitrogen fertilizers were at no date effective in causing statistically important reductions in dead cotton.

The plant characters used as indices of development in these studies were recorded on June 15 and 29 and on July 13 and 27. The 3–9–3 fertilizer definitely accelerated development of the cotton, with significant increases in heights of plants and in numbers of squares through the middle of July, in comparison with the unfertilized check plats. The number of bolls showed an increase also on June 29. The effect of the 0–15–0 fertilizer was somewhat less pronounced; however, height and number of squares were increased on June 15 and height and numbers of bolls were greater on July 13. The 9–3–3 fertilizer caused an increase in number of squares on June 29 and in height of plants on July 13. Nitrogen alone (15–0–0) did not at any time have a significant effect on the plant characters studied except for a reduction in number of bolls on July 27. This field was heavily infested with insects during the latter part of the season, which may have disturbed the trend of fertilizer effects.

DISCUSSION

On the Wilson soils there is but a partial correlation of plant development and the incidence of root-rot. There appears to be a definite acceleration of development by the 0–15–0 fertilizer and this effect is accompanied by a statistically important increase in the amount of root-rot on these plats. While there is a definite decrease in the amount of root-rot on the 15–0–0 plats, these plants show but a tendency towards a prolongation of the fruiting stage, without materially increasing yields.

The effect of the 3–9–3 ratio is to accelerate development, but its relation to root-rot is variable. A summation of the data from these plats shows that the average result is that of increasing the mortality of cotton plants. Although the summary gives an amount not of statistical importance, a study of individual records, as given in Table 1. reveals that both increases and decreases have been produced. In either case some of the differences are of statistical importance. This dual behavior is thought to be associated with seasonal conditions, rate of application of the fertilizer, and probably other factors.

The more apparent anomaly is that of the 9–3–3 fertilizer. Its effect

is to stimulate plant development to an extent comparable with that of the 3-9-3 ratio, but it reduced root-rot by a significant margin.

The 1-year study on Houston black clay shows an acceleration of development due to the 3-9-3 fertilizer and to a lesser extent to the 0-15-0 and 9-3-3 ratios, in the order named. There are associated increases in root-rot prevalence caused by the 0-15-0 and 3-9-3 ratios. Nitrogen alone was not effective in changing either the plant characters studied or percentages of dead cotton.

Visual differences in the general appearance of unfertilized plants and those grown in the field with high-nitrogen and high-phosphate fertilizers are greater than is indicated by the studies presented. When the phosphate-fed plants show decided evidence of maturity the nitrogen-fed plants retain their vegetative characteristics, with large, dark-green leaves and the continuation of fruiting. Unfertilized plants are intermediate with respect to these characters.

The soils used differ in their response to fertilizers. A ratio in which the amount of phosphate exceeds that of nitrogen is indicated for the Wilson series, while the converse is indicated for the Houston black clay. The effect of potash is more outstanding on the lighter-textured Wilson soils.

SUMMARY

Cotton was grown on Wilson clay loam, Wilson fine sandy loam, and Houston black clay soils, using fertilizers of 0-15-0, 3-9-3, 9-3-3, and 15-0-0 analyses. Periodic records were made of the numbers of plants killed by root-rot, of the height, and numbers of squares and bolls.

Under the conditions of the experiment, an analysis of variance for four fields located on the Wilson soil showed that the 15-0-0 and 9-3-3 fertilizers reduced the number of plants killed by root-rot and that the 0-15-0 increased the mortality by amounts of statistical importance. The 3-9-3 ratio may either increase or decrease the kill as shown by individual records, but a summation indicated an increase which was not of importance. Differences on the Houston soil were confined to the 0-15-0 and 3-9-3 ratios. For the first two dates of record the increases effected by the 0-15-0 were of importance, while that of the 3-9-3 occurred on the first date.

Phosphate alone and the complete fertilizers accelerated the development of the plant when height and numbers of squares and bolls were considered as indices; during the earlier part of the season the increases are generally of statistical importance. On the Houston soil the effect is produced by the 3-9-3, 0-15-0, and 9-3-3 fertilizers. Nitrogen alone (15-0-0) only tends to delay development.

A correlation of an acceleration of plant development and the incidence of root-rot is indicated for the 0-15-0 fertilizer. The variable relation of the complete ratios and the tendencies for the 15-0-0 ratio are discussed.

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NOTE

THE CENTER OF MEMBERSHIP FOR THE AMERICAN SOCIETY OF AGRONOMY

THE geographical distribution of the members of the American Society of Agronomy is naturally one factor which should be taken into consideration in selecting the place for the annual meeting. It should be possible to determine the location of a centroid such that 100% attendance at a meeting held at this place would require a minimum number of man-miles of travel. Railroad or highway distances should, of course, be used in such a calculation, but this would complicate the problem considerably. Shortest airline distances may be approximated by expressing locations in terms of latitude and longitude.

The names and addresses of the 1,103 members of the Society within the continental United States were kindly supplied by the Secretary. Making use of maps, the latitude and longitude values for individual members were estimated to the closest tenth of a degree. Locations for a few individuals were not given on maps which were conveniently available. These individuals were arbitrarily assigned central locations in their respective states.

Because of possible usefulness in calculating regional centroids, the sum of the latitude and longitude values for the members of each state was tabulated and is submitted in Table 1. The average latitude and longitude values for the whole membership in the United States were found to be, respectively, 39.3 and 90.3 degrees. The membership centroid thus lies in the state of Illinois about 45 miles due north of St. Louis, Missouri.

No correction has been made for a small error in the longitude of the centroid arising from the fact that the number of miles along the earth's surface for 1 degree change of longitude varies with the latitude.

Since the latitude and longitude for each member of the Society has been tabulated on the membership list, it would be an easy matter to determine to what extent the place of the annual meeting effects the centroid of members attending the meeting.—L. A. RICHARDS, *Iowa State College, Ames, Iowa.*

TABLE 1.—*Latitude and longitude values for members of the American Society of Agronomy by states.*

State	Number of members	Latitude	Longitude
Alabama	18	589.4	1,538.1
Arizona	11	355.7	1,223.2
Arkansas	10	357.3	934.0
California	44	1,630.7	5,317.8
Colorado	21	834.3	2,187.2
Connecticut	15	621.3	1,093.2
Delaware	3	119.1	227.0
District of Columbia	91	3,530.8	7,007.0
Florida	20	592.0	1,653.2
Georgia	19	632.1	1,589.1
Idaho	8	369.1	932.6
Illinois	48	1,940.8	4,250.5
Indiana	31	1,247.3	2,691.6
Iowa	63	2,626.9	5,896.8
Kansas	51	1,991.2	4,931.0
Kentucky	12	454.1	1,023.5
Louisiana	15	459.7	1,274.8
Maine	9	405.0	617.6
Maryland	19	747.5	1,461.5
Massachusetts	12	507.4	870.1
Michigan	22	939.7	1,860.2
Minnesota	33	1,527.1	3,161.2
Mississippi	15	499.4	1,336.3
Missouri	34	1,331.3	3,139.2
Montana	9	414.2	997.9
Nebraska	28	1,144.8	2,732.6
Nevada	2	76.8	234.0
New Hampshire	2	86.6	141.8
New Jersey	14	567.2	1,041.1
New Mexico	11	388.2	1,180.8
New York	47	1,978.8	3,556.4
North Carolina	22	791.2	1,738.6
North Dakota	15	706.2	1,494.2
Ohio	52	2,093.6	4,291.7
Oklahoma	17	613.7	1,657.6
Oregon	20	891.0	2,448.6
Pennsylvania	30	1,221.6	2,317.1
Rhode Island	7	283.7	500.8
South Carolina	14	478.6	1,142.4
South Dakota	10	441.4	976.9
Tennessee	9	324.0	755.1
Texas	57	1,810.0	5,548.5
Utah	14	573.1	1,567.0
Vermont	3	132.1	216.3
Virginia	24	894.9	1,895.8
Washington	21	983.8	2,479.2
West Virginia	15	602.2	1,199.0
Wisconsin	32	1,388.6	2,864.8
Wyoming	4	164.6	420.1
Total	1,103	43,360.1	99,615.0
Average		39.3	90.3

BOOK REVIEW

A B C OF AGROBIOLOGY

By O. W. Willcox. New York: W. W. Norton & Co., Inc. 323 pages, illus. 1937. $2.75.

AGROBIOLOGY is defined as "the universal quantitative science of plant growth." It is "not concerned with the ecology, physiology, parasitology, pathology, or climatology of plants." It "steers away from the idiosyncrasies and the infinite superficial divergences that exist among the multitudinous forms of plants" and considers those "characteristics and capabilities that are common to all species and varieties." "A universal science of plant growth is possible because roses, tomatoes, rubber trees, sugar cane, onions, garden beets, tulips, orange trees, tea bushes, and all other vegetable organisms that send their roots into the earth and branches into the air have in common certain fundamentally identical characteristics, and react in an identical manner to the same universal factors on which they all depend for their life and growth. . . .

"Because all plants have fundamentally identical natures and react in an identical manner to the same positive external stimulants, the agrobiologists have been enabled to devise an arithmetic of plant growth by which yields may be figured in terms of a known degree of fertility of the soil; or, *vice versa*, to figure how much fertility will be required to produce a desired yield, even the maximum. So that if the gardener or farmer knows in advance how much life is in his seeds and knows what quantity of the factors of plant growth he has at his disposal, he may proceed in the confidence that the harvest will turn out close to what was expected, whether he is growing onions, roses, wheat, gladioli, or whatnot."

These quotations from Chapter I epitomize the philosophy of this book. Mitscherlich is regarded as the founder of the science. His "law of the minimum" is the fundamental principle underlying this "universal science of plant growth". Its fundamental yardstick is the "Baule unit" which is defined as the amount of the limiting factor necessary to produce one-half of the maximum yield. The second Baule unit increases the yield to 75% of the maximum, etc. The tenth unit gives 99.99% of the maximum and for practical purposes this is considered as the "perultimate yield." One Baule unit of nitrogen is regarded as 225 pounds per acre, of phosphoric acid 45, and of potash 82 pounds per acre. The "perfertile" soil should contain 10 Baule units of all the essential elements. Water needs are handled in the same way. The author is apparently unfamiliar with the extensive investigations of Veihmeyer and his co-workers at California.

The absolute size of the maximum yield of any crop is determined by certain internal factors referred to as the "quantity of life." The agrobiologists have a yardstick for this also. This is derived by an analysis of the proportion of the nitrogen present which is actually utilized by plants. The maximum amount which can be absorbed from a perfertile soil is considered to be 318 pounds per acre. A variety of crop plant that can utilize 318 pounds of nitrogen per acre "is the *ne plus ultra* of the plant breeder." By dividing this "constant of

nature" by the actual percentage of nitrogen in any crop we can obtain the maximum possible yield for the species beyond which the plant breeder cannot hope to go! The calculated theoretical yield for corn is 225 bushels (this has been attained), wheat, 171.2 bushels; potatoes, 1,550 bushels (somewhat less than the yield reported from California for water cultures!), sugar cane, 192 tons; and cotton, 4.6 bales.

One chapter is devoted to "Public Soil Science in the United States." A few hot shots are taken at the Soil Survey and of agronomists who refuse to become enthusiastic over the use of chemical analysis as a means of determining fertilizer needs. The author recommends "that if 'leading' agricultural colleges and experiment stations discover among their ranking officials men who can see no correlation between chemical soil analysis and crop response to fertilizer, such officials should forthwith be given sabbatical leave as observers at the Virginia Truck Experiment Station, or some other institution of the same grade."

In addition to being the A B C of Agrobiology one gets the impression that this book is also the X Y Z of the subject. Its problems are solved! The job is done. Its laws are all discovered. They are immutable and universal; any deviations therefrom are to be attributed to certain "sources of frustration" with which the agrobiologist is not concerned. These "sources of frustrations" are left in the lap of the agronomist and other less ethereal groups of scientists. (R. B.)

AGRONOMIC AFFAIRS

THE SOIL CONSERVATION SERVICE GRASS NURSERY AT ITHACA, NEW YORK

AGRONOMISTS and others interested in grasses and legumes, when visiting Ithaca, N. Y., will want to spend some time at the Soil Conservation Service, Region 1, Grass Nursery located at Stewart Park.

The Grass Nursery occupies 19 acres of land planted to observational material and 46 acres which are used for increase plots. Here are more than 600 varieties and species of grasses and legumes brought together for study and comparison in order to determine which are best for the various phases of erosion control.

The work is under the direction of Raymond E. Culbertson who extends an open invitation to visitors.

A SURVEY OF PASTURE EXPERIMENTS

THE National Fertilizer Association has issued a mimeographed survey of pasture experiments now in progress in the humid sections of the United States prepared by H. R. Smalley and A. L. Grizzard. Copies will be supplied as long as the supply lasts.

In all, 133 projects are listed in 35 states, including more than 300 distinct experiments. In addition to the title and objectives of the project, information is supplied wherever available on the leader, date of initiation, location, source of support, size of plots, fertility treatment, seeding mixtures, methods used in measuring response, chemical analyses, and publications.

NEWS ITEMS

IT HAS been announced that Professor Juan Diaz y Munoz, the well-known Spanish soil investigator and director of general agriculture in Spain, fell as a victim of the Spanish Civil War. American soil workers who attended the last International Soil Science Congress in Oxford will well remember the tall figure of the always smiling Spanish scientist. He was a student of Professor Wiegner and contributed considerably to our knowledge of the soils of Spain.

DOCTOR M. F. MILLER, Chairman of the Department of Soils, College of Agriculture, University of Missouri, since 1914, will become Dean and Director of the Missouri Agricultural College and Experiment Station on September 1 next.

THE MEETING of the Corn Belt Section of the Society will be held June 22 and 23 at the Missouri Agricultural Experiment Station and will be preceded by a celebration on June 21 of the 50th anniversary of the establishment of the Experiment Station.

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EFFECT OF SPACING ON THE DEVELOPMENT OF THE FLAX PLANT[1]

A. C. DILLMAN and J. C. BRINSMADE, JR.[2]

IT is a matter of common observation that the growth habits of plants are modified by the space available for their development. Numerous experiments have been conducted to determine the effect of spacing on the plant development and yield of cotton, corn, tobacco, beets, potatoes, and other row crops, and of the small grains. The spacing of flax grown for fiber also has been studied extensively because of the close relation between the stand of plants and the yield, length, and quality of fiber. Few such investigations have been conducted with varieties of flax grown for seed production.

In 1920, Clark[3] reported on the yield and agronomic data of 49 varieties and strains of flax grown at Mandan, N. D., in 1914 to 1916, and Klages,[4] in 1932, reported the results of spacing experiments conducted at Brookings, S. D., in 1930 and 1931.

The experiments herein reported were planned to determine the effect of spacing on the branching habit, height, time of maturity, and yield of seed per plant and per unit area of typical varieties of seed flax.

THE FLAX PLANT

The flax plant has three distinct types of branches, namely, (1) basal branches which arise in pairs (i. e., as opposite branches) from the crown of the plant; (2) panicle branches which bear the seed bolls; and (3) adventitious branches which occasionally occur on the main stem. In close spacing the basal branches may be partly or entirely suppressed, whereas, in wide spacing several basal branches may occur. The panicle is formed by the dichotomous branching of the upper part of the stem, each small branch usually terminating in a seed boll. Adventitious branches seldom occur in close stands. They occur most

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication December 17, 1937.

[2]Associate Agronomist and Assistant Agronomist, respectively.

[3]CLARK, C. H. Experiments with flax on breaking. U. S. D. A. Bul. 883. 1920.

[4]KLAGES, K. H. Spacing in relation to the development of the flax plant. Jour. Amer. Soc. Agron., 24:1–17. 1932.

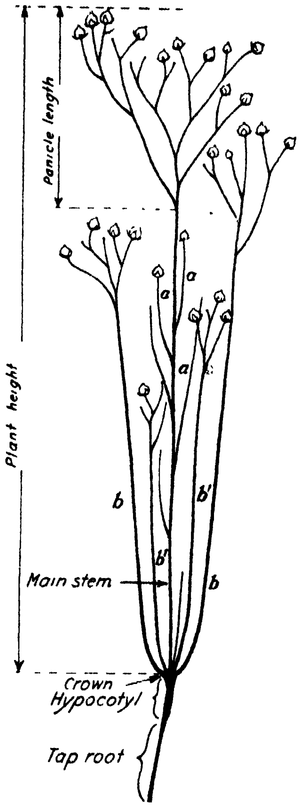

FIG. 1.—Diagram of flax plant showing first pair of basal branches (b-b), second pair of basal branches (b'-b'), and adventitious branches (a). The diameter of main stem is measured at a point 4 or 5 inches above the crown.

commonly on widely spaced plants, or in case the plants are broken down, or when late rains stimulate a secondary vegetative growth (Fig. 1).

LOCATION OF THE EXPERIMENTS

The experiments reported in this paper were conducted at the Northern Great Plains Field Station, Mandan, N. D., in 1916, and during the four years, 1926 to 1929, inclusive. The average annual precipitation at Mandan is approximately 16 inches of which about 12 inches occur during the crop growing season of April to August, inclusive. Drought frequently occurs, however, and it is perhaps the chief limiting factor to otherwise successful crop production in that locality.

EXPERIMENTAL METHODS

The first spacing experiments herein reported were conducted in 1916, using a single variety, Reserve, C. I. 19 During the four years, 1926 to 1929, two varieties were grown, Linota, a selection of the small-seeded short-fiber type, and Rio, a selection of the large-seeded Argentine type. The plants were grown in six definite spacings; in close-drilled plats, the rows 6 inches apart and the plants about ½ inch apart in the row; and in rows 12 inches apart with the plants spaced 1, 2, 3, 4, and 6 inches apart in the row. The seed was sown somewhat thicker than required for the desired stand and the plants thinned to the proper spacing when 1 to 2 inches high. The plats were cultivated and kept entirely free from weeds.

When ripe the plants were pulled, wrapped separately, and hung up to dry, after which the measurements were taken and the seed threshed. In 1929, the more satisfactory procedure of recording the measurements of 50 or more plants as they were pulled and then threshing the plants in bulk after drying, was followed.

The notes included height of plant, length of panicle, number of basal branches, number of bolls on the main stem and on the basal branches, weight of seed, and weight of 1,000 seeds.

RESULTS OBTAINED IN 1916

The variety Reserve (C. I. 19), a strain of the so-called common or Russian seed flax, was grown in the spacing experiments in 1916. Six plats of four rows 1 foot apart were sown, leaving the plants 1, 2, 3, 4, 5, and 6 inches apart, respectively, in the rows. The two inner rows in each plat were harvested, leaving a border row on each side of the plat in which the plants were spaced the same as in the harvested rows.

The crop of 1916 was grown on virgin soil. The native sod was plowed in 1914 and kept fallow in 1915, a season of abundant rainfall. At the time of seeding the soil was moist to a depth of 6 feet or more, and although the seasonal rainfall was below normal, the crop did not appear to be checked appreciably from lack of moisture. The seasonal precipitation, April to August, was 10.5 inches (Table 3).

Some loss of plants from "heat canker" occurred after the rows were thinned, so that the spacing at time of harvest was not entirely uniform. The average spacing at time of harvest ranged from 1.1 inches in plat 1, the closest spacing, to 7.3 inches in plat 6, the widest spacing. The plants probably were somewhat more variable than they would have been if a uniform stand had been maintained. Where a plant is missing from any cause the adjacent plants are likely to be larger because of the extra space available for their development. In the experiments of 1916, all the plants in each plat were pulled. In the later experiments only plants which were spaced correctly were harvested, that is, plants adjacent to a space marking a missing plant were not harvested.

A summary of the average values of the several plant characters measured in 1916 is presented in Table 1. The number of plants measured was sufficient for an adequate sample of each spacing, the number ranging from 234 plants in the 4-inch spacing to 513 plants in the 1-inch spacing.

The average height of plants ranged from 50 cm in the 1-inch spacing to 55 cm in the 3-inch spacing, an extreme range of only 5 cm.

The length of panicle of the main stem, as measured from the base of the lowest panicle branch to the tip of the panicle, ranged from 15.7 cm in the 1-inch spacing to 25.6 cm in the 5-inch spacing.

The number of basal branches appears to be dependent on the space available to the plant for development. In the experiments of 1916, the average number of basal branches ranged from 0.2 per plant in plat 1 to 2.7 in plat 6. As mentioned previously, the basal branches occur in pairs so that there is a tendency for the plants in wider spacing to have two, or frequently four, basal branches. In many plants, however, one branch of the pair is suppressed. Typical plants in 1-inch spacing had no basal branches, all being suppressed. In Table 2 the percentage of plants having from 0 to 6 basal branches is recorded.

The number of bolls on the panicle of the main stem and on the basal branches were recorded separately. Since there were very few basal branches in the 1-inch spacing, the bolls occurred chiefly on the panicle of the main stem. The total number of bolls increased more or less regularly from the 1-inch to the 6-inch spacing, the number ranging

TABLE 1.—*Average plant measurements of Reserve flax spaced from 1 to 6 inches apart in rows 1 foot apart at Mandan, N. D., in 1916.*

Plant measurements	Plat No. 1	Plat No. 2	Plat No. 3	Plat No. 4	Plat No. 5	Plat No. 6
Spacing, inches:						
Theoretical, as first spaced.	1	2	3	4	5	6
Actual, at time of harvest. .	1.1	2.3	3.3	4.9	5.7	7.3
Number of plants measured. .	513	252	264	234	252	238
Height, cm.	50.0	53.3	55.1	54.0	54.3	54.3
Length of panicle, cm.	15.7	20.5	24.3	24.6	25.6	24.9
Number of basal branches. . .	0.2	0.8	1.8	2.2	2.2	2.7
Number of bolls:						
On main stem.	12	22	27	34	32	32
On basal branches.	1	4	12	19	18	24
Total per plant	13	26	39	53	50	56
Yield:						
Seeds per boll.	6.5	6.3	5.9	5.5	6.1	6.3
Seed per plant, grams.	0.39	0.75	1.05	1.34	1.38	1.60
Bushels per acre	7.1	6.8	6.6	5.6	5.0	4.6
Weight of 1,000 seeds, grams.	4.61	4.61	4.57	4.56	4.50	4.52
Oil content on dry basis, %. .	39.0	39.2	38.9	38.3	38 8	38.8
Iodine value, Wijs method. . .	177	177	177	175	174	176

TABLE 2.—*The effect of spacing on the number of basal branches in Reserve flax plants grown at Mandan, N. D., 1916.*

Spacing, inches	Number of plants	Number of basal branches and percentage of plants in each group						
		0	1	2	3	4	5	6
1	513	90	5	4	1	0	0	0
2	252	56	17	23	2	2	0	0
3	264	18	17	46	12	7	0	0
4	234	6	13	39	26	16	0	0
5	252	5	18	39	18	18	2	0
6	238	1	6	36	27	27	2	1

from 13 per plant in the 1-inch spacing to 56 per plant in the 6-inch spacing.

The yield of seed per plant is, of course, directly correlated with the number of bolls. The yield of seed increased from 0.39 gram per plant in the 1-inch spacing to 1.6 grams in the 6-inch spacing. The increase in the wider spacing, however, was not in proportion to the space available and, therefore, the yield per unit area decreased as the spacing increased. The computed yield ranged from 7.1 bushels per acre in the 1-inch spacing to 4.6 bushels in the 6-inch spacing (Table 1).

The comparative size of the seeds of flax is conveniently expressed by the weight of 1,000 seeds. In this experiment there was no significant difference in weight of 1,000 seeds, nor in the oil content, nor in the iodine number of the oil, as determined by analyses of seed samples from the several spacings. The weight of 1,000 seeds averaged approxi-

mately 4.55 grams, the oil content 38.8% on dry basis, and the iodine number 176 (Table 1).

RESULTS OBTAINED 1926 TO 1929

As previously mentioned, two varieties, Linota and Rio, were grown in the spacing experiments from 1926 to 1929, inclusive. Seasonal rainfall and somewhat different soil conditions are sufficient to account for the variation in plant characters observed during the four seasons. In 1926 and 1927 the experimental plats were on soil that had grown flax the previous season; in 1928, the crop was grown on bromegrass sod plowed the previous summer; and in 1929, on adjacent sod land kept fallow in 1928. The seasons of 1926 and 1929 were relatively dry, while 1927 and 1928 were above normal in total rainfall. However, the months of June and July, 1927, were dry, and the early season of 1928 (May to June 12) was extremely dry. The rainfall in inches during the crop growing season, the evaporation from a free-water surface, and the ratio of precipitation to evaporation each season are shown in Table 3.

TABLE 3.—*Seasonal precipitation, evaporation from a free water surface, and ratio of precipitation to evaporation in 1916 and in 1926 to 1929 at Mandan, N. D.*

	Precipitation, inches				
	1916	1926	1927	1928	1929
Apr.	0.93	0.13	1.37	0.99	1.75
May	1.69	2.41	6.65	0.55	2.68
June	2.25	1.20	2.00	6.32	0.99
July	3.55	2.19	2.37	4.94	1.20
Aug	2.04	1.31	3.16	2.24	0.81
Total	10.46	7.24	15.55	15.04	7.43
Evaporation, Apr. to Aug.	26.88	30.77	24.25	27.77	29.82
Ratio, Prec/Evap.	0.39	0.24	0.64	0.54	0.25

The number of plants measured in each spacing was 50 or 100 in most cases. In the wider spacings, however, there was some loss of plants from heat canker, especially in 1926, and in such cases somewhat less than 50 plants were available for measurement. In a few plats in close stands over 200 plants were measured. A summary of the several characters measured is given in Tables 4 and 5.

In these tables, the plats referred to as "close stand" were sown in drill rows 6 inches apart and there were approximately 24 plants per foot of row, or 48 plants per square foot. In all other plats the rows were 12 inches apart and the plants spaced approximately 1, 2, 3, 4, and 6 inches apart in the row, that is, there were 12, 6, 4, 3, and 2 plants, respectively, per square foot of space.

TABLE 4.—*Average plant measurements of Linota and Rio flax grown in six spacings at Mandan, N. D., 1926 to 1929.*

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average
	A. Number of Plants Measured				
Linota:					
Close stand	200	100	50	50	
1 inch	280	100	50	50	
2 inches	100	100	50	50	
3 inches	80	73	50	50	
4 inches	60	54	50	50	
6 inches	40	30	50	50	
Rio:					
Close stand	200	100	50	50	
1 inch	100	100	50	50	
2 inches	70	100	50	50	
3 inches	40	100	50	50	
4 inches	30	80	42	50	
6 inches	15	55	45	50	
	B. Height of Plants, cm				
Linota:					
Close stand	23.2	43.6	61.4±.51	43.8±.39	43.0
1 inch	41.2	57.4	71.0±.61	57.8±.35	56.9
2 inches	48.3	63.3	73.0±.76	59.6±.23	61.1
3 inches	51.5	64.3	75.1±.55	62.1±.34	63.3
4 inches	57.0	65.4	74.7±.70	60.6±.39	64.4
6 inches	57.0	63.1	69.0±.87	59.8±.39	62.2
Rio:					
Close stand	23.2	36.8	55.7±.48	39.3±.42	38.8
1 inch	43.6	41.0	65.7±.46	46.3±.37	49.2
2 inches	49.1	45.0	63.2±.50	51.9±.39	52.3
3 inches	50.8	45.6	64.0±.63	55.3±.41	53.9
4 inches	55.4	46.7	60.0±.58	54.9±.35	54.3
6 inches	54.0	45.5	58.4±.51	54.7±.44	53.2
	C. Diameter of Main Stem, mm				
Linota:					
Close stand	0.83	1.12	1.36±.03	1.34±.02	1.16
1 inch	1.61	1.88	2.15±.03	2.20±.02	1.96
2 inches	2.10	2.28	2.54±.02	2.33±.01	2.31
3 inches	2.30	2.59	2.93±.02	2.51±.02	2.58
4 inches	2.51	3.00	3.04±.04	2.65±.02	2.80
6 inches	2.94	3.08	3.48±.04	2.87±.03	3.09
Rio:					
Close stand	0.98	1.44	1.22±.03	1.39±.01	1.26
1 inch	1.92	1.67	2.08±.02	1.64±.02	1.83
2 inches	2.06	1.86	2.32±.02	1.91±.02	2.04
3 inches	2.45	2.03	2.48±.02	2.10±.02	2.27
4 inches	2.93	2.34	2.64±.03	2.16±.02	2.52
6 inches	2.82	2.29	2.77±.04	2.42±.03	2.58

TABLE 4.—*Continued.*

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average
	D. Number of Basal Branches				
Linota:					
Close stand......	0.0	0.0	0.0	0.0	0.0
1 inch.	0.6	0.5	1.8	1.9	1.2
2 inches...	2.2	2.0	2.3	3.0	2.4
3 inches...... .	3.4	2.7	4.1	3.9	3.5
4 inches...... ...	3.9	3.2	4.1	4.1	3.8
6 inches..	5.0	4.2	4.3	5.5	4.8
Rio:					
Close stand......	0.1	0.2	0.0	0.2	0.1
1 inch ..	3.2	1.7	2.3	3.3	2.6
2 inches.... .	3.8	3.2	3.9	4.3	3.8
3 inches..	5.8	3.5	4.1	6.2	4.9
4 inches	6.1	3.7	5.2	7.1	5.5
6 inches	7.5	4.2	6.7	8.0	6.6
	E. Number of Bolls				
Linota:					
Close stand:					
Main stems..	2.0	3.5	5.4	5.1	4.0
1 inch:					
Main stems...	10.1	15.3	13.3	18.0	14.2
Basal branches	1.2	10.3	4.7	5.8	5.5
Total per plant.	11.3	25.6	18.0	23.8	19.7
2 inches:					
Main stems....	17.6	25.8	21.5	19.7	21.2
Basal branches.	10.2	10.4	12.4	12.1	11.3
Total per plant.	27.8	36.2	33.9	31.8	32.5
3 inches:					
Main stems....	23.0	32.6	28.8	25.2	27.4
Basal branches.	21.4	20.3	29.7	24.6	24.0
Total per plant	44.4	52.9	58.5	49.8	51.4
4 inches:					
Main stems...	26.7	39.8	35.4	29.8	32.9
Basal branches.	26.0	29.7	32.8	38.1	31.7
Total per plant.	52.7	69.5	68.2	67.9	64.6
6 inches:					
Main stems....	36.9	39.3	43.8	35.5	38.9
Basal branches.	39.2	45.6	51.0	49.1	46.2
Total per plant.	76.1	84.9	94.8	84.6	85.1
Rio:					
Close stand:					
Main stems....	1.0	6.5	3.5	1.1	3.0
1 inch:					
Main stems....	8.2	10.9	14.8	2.7	9.2
Basal branches.	12.2	4.8	14.1	7.5	9.7

TABLE 4.—*Continued.*

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average
	E. Number of Bolls—*Continued*				
Rio:					
Total per plant.	20.4	15.7	28.9	10.2	18.9
2 inches:					
Main stems. . .	10.7	16.9	19.2	4.1	12.7
Basal branches.	18.3	15.8	29.1	18.1	20.3
Total per plant.	29.0	32.7	48.3	22.2	33.0
3 inches:					
Main stems. . .	18.8	23.6	21.6	7.0	17.8
Basal branches.	39.5	22.3	41.1	30.5	33.4
Total per plant.	58.3	45.9	62.7	37.5	51.2
4 inches:					
Main stems. . . .	25.6	31.6	29.5	7.3	23.5
Basal branches	55.6	27.3	53.4	38.1	43.6
Total per plant	81.2	58.9	82.9	45.4	67.1
6 inches:					
Main stems. . . .	24.2	32.0	30.1	12.6	24.7
Basal branches.	65.5	32.8	65.0	48.7	53.0
Total per plant.	89.7	64.8	95.1	61.3	77.7
	F. Seed per Plant, grams				
Linota:					
Close stand	0.04	0.11	0.10	0.12	0.09
1 inch.	0.23	0.36	0.34	0.41	0.34
2 inches	0.76	0.73	0.92	0.63	0.76
3 inches.	0.99	1.23	1.30	1.14	1.17
4 inches.	1.27	1.78	1.66	1.47	1.55
6 inches.	1.84	2.11	2.21	1.62	1.95
Rio:					
Close stand	0.02	0.18	0.14	0.03	0.09
1 inch.	0.38	0.53	0.88	0.16	0.49
2 inches.	0.67	1.31	1.41	0.56	0.99
3 inches.	1.70	1.66	1.96	0.96	1.57
4 inches.	1.80	2.22	2.86	1.24	2.03
6 inches.	2.24	2.53	3.62	1.92	2.58
	G. Weight of 1,000 Seeds, grams				
Linota:					
Close stand.	3.07	3.98	3.70	2.76	3.38
1 inch.	3.21	4.07	3.73	2.77	3.45
2 inches.	3.23	4.18	3.79	2.83	3.51
3 inches	3.38	4.07	3.75	3.07	3.57
4 inches.	3.40	4.03	3.73	3.12	3.57
6 inches.	3.48	4.10	3.85	3.11	3.64
Annual average	3.30	4.07	3.76	2.94	3.52

TABLE 4—*Concluded.*

Variety and spacing	Measurements recorded				
	1926	1927	1928	1929	Average
	Weight of 1,000 Seeds, grams—*Continued*				
Rio:					
Close stand	5.60	6.86	6.53	5.52	6.13
1 inch	5.78	6.84	6.53	5.75	6.23
2 inches	5.90	7.29	6.38	5.92	6.37
3 inches	6.00	7.48	6.53	5.84	6.46
4 inches	5.78	7.27	6.27	5.96	6.32
6 inches	5.78	7.61	6.64	5.90	6.48
Annual average	5.81	7.23	6.48	5.82	6.33
	H. Computed Yield in Bushels per Acre*				
Linota:					
Close stand	3.3	9.1	8.2	8.1	7.2
1 inch	4.7	7.4	7.0	7.6	6.7
2 inches	7.8	7.5	9.5	7.1	8.0
3 inches	6.8	8.5	9.0	7.5	8.0
4 inches	6.5	9.1	8.5	7.1	7.8
6 inches	6.3	7.2	7.5	6.1	6.8
Rio:					
Close stand	1.6	14.8	11.5	3.2	7.8
1 inch	7.8	10.9	18.1	4.4	10.3
2 inches	6.9	13.5	14.5	5.0	10.0
3 inches	11.7	11.5	13.5	5.8	10.6
4 inches	9.2	11.3	14.6	5.6	10.2
6 inches	7.6	8.6	12.3	6.3	8.7

*Yield in 1926, 1927, and 1928 is computed on the basis of seed per plant (Table 4 F) and full stand of plants, that is, 824 plants per plat in close stand, 206 plants per plat spaced 1 inch apart, 103 plants spaced 2 inches, 69 plants spaced 3 inches, 51 plants spaced 4 inches, and 34 plants spaced 6 inches. In 1929, all plants were harvested and the acre yield is based on the actual yield per plat.

DISCUSSION

In reviewing the results of the experiments from 1926 to 1929 (Tables 4 and 5), it is of interest to note (1) the effects of spacing, (2) the effect of season, principally rainfall, and (3) the behavior of the two varieties. The seasons of 1927 and 1928 were fairly favorable, whereas 1926 and 1929 were relatively dry.

In height, the plants in close stand were of shorter growth in every case. In the 12-inch rows there was some increase in height from the 1-inch to the 4-inch spacing. In most cases the plants in the 6-inch spacing were shorter than in the 4-inch spacing. The effect of season (rainfall) on height of plants was marked as may be seen by comparing 1926 and 1928 or 1928 and 1929. Seasonal effects were perhaps greater than varietal differences.

In diameter of the main stem there was a marked and constant increase in size of stems as the spacing increased. Moreover, the diameter of the stems was very uniform in each spacing as shown by the small probable error in the measurements of 1928 and 1929. The stems of Linota were larger than those of Rio, except in close stands. No doubt

TABLE 5.—*Oil content and iodine number (Wijs method) of Linota and Rio flax plants grown in six spacings at Mandan, N. D., 1928 to 1929.*

Spacing	Oil content (dry basis), %			Iodine No.		
	1928	1929	Average	1928	1929	Average
			Linota			
Close spacing	36.4	33.2	34.8	182	169	176
1 inch	36.5	33.1	34.8	182	171	177
2 inches	36.4	33.5	35.0	186	174	180
3 inches	36.9	34.1	35.5	186	179	183
4 inches	37.3	34.5	35.9	187	179	183
6 inches	37.8	34.1	36.0	188	180	184
Annual average	36.9	33.8	—	185	175	—
			Rio			
Close spacing	39.6	37.5	38.6	180	171	176
1 inch	40.9	38.6	39.8	180	174	177
2 inches	40.3	38.7	39.5	179	177	178
3 inches	41.2	38.9	40.1	183	175	179
4 inches	41.7	38.9	40.3	185	176	181
6 inches	41.5	40.0	40.8	186	177	182
Annual average	40.9	38.8	—	182	175	—

this difference is associated with the number of basal branches. The development of a greater number of basal branches on Rio than on Linota had the effect of reducing the growth of the main stem, somewhat as the closer spacing did.

The number of basal branches is determined chiefly by the space available and to a less extent probably by seasonal conditions and by variety. The average number of basal branches in Linota ranged from 0 in close stand to 4.8 per plant in the 6-inch spacing, and in Rio from 0.2 in close stand to 6.6 per plant in the 6-inch spacing (Fig. 2).

The number of bolls per plant (Table 4, E) was not significantly different in the two varieties. The average in Linota ranged from 4.0 per plant in close stand to 85.1 in the 6-inch spacing and in Rio from 3.0 in close stand to 77.7 per plant in the 6-inch spacing.

In average yield of seed per plant (Table 4, F), Linota ranged from 0.9 grams in close stand to 1.94 grams in the 6-inch spacing and Rio from 0.09 to 2.58 grams. The yield of seed is, of course, closely correlated with the number of bolls per plant, that is, within each variety. The yield, however, is determined in part by the size of seeds, and by the number of seeds per boll. The average weight of 1,000 seeds of Linota was 3.52 grams as compared with 6.33 grams for Rio, a ratio of 1:1.8. On the average, the yield of seed from 100 bolls of Linota was 2.27 grams and from Rio 3.09 grams, a ratio of 1:1.36. On the average, therefore, Linota had 6.4 seeds per boll and Rio 4.9 seeds per boll. The flax boll when filled has 10 seeds, rarely or never any more, except in abnormal twin bolls.

The computed yield of seed in bushels per acre, based on a full stand, is given for 1926, 1927, and 1928, whereas the actual yield in 1929 is

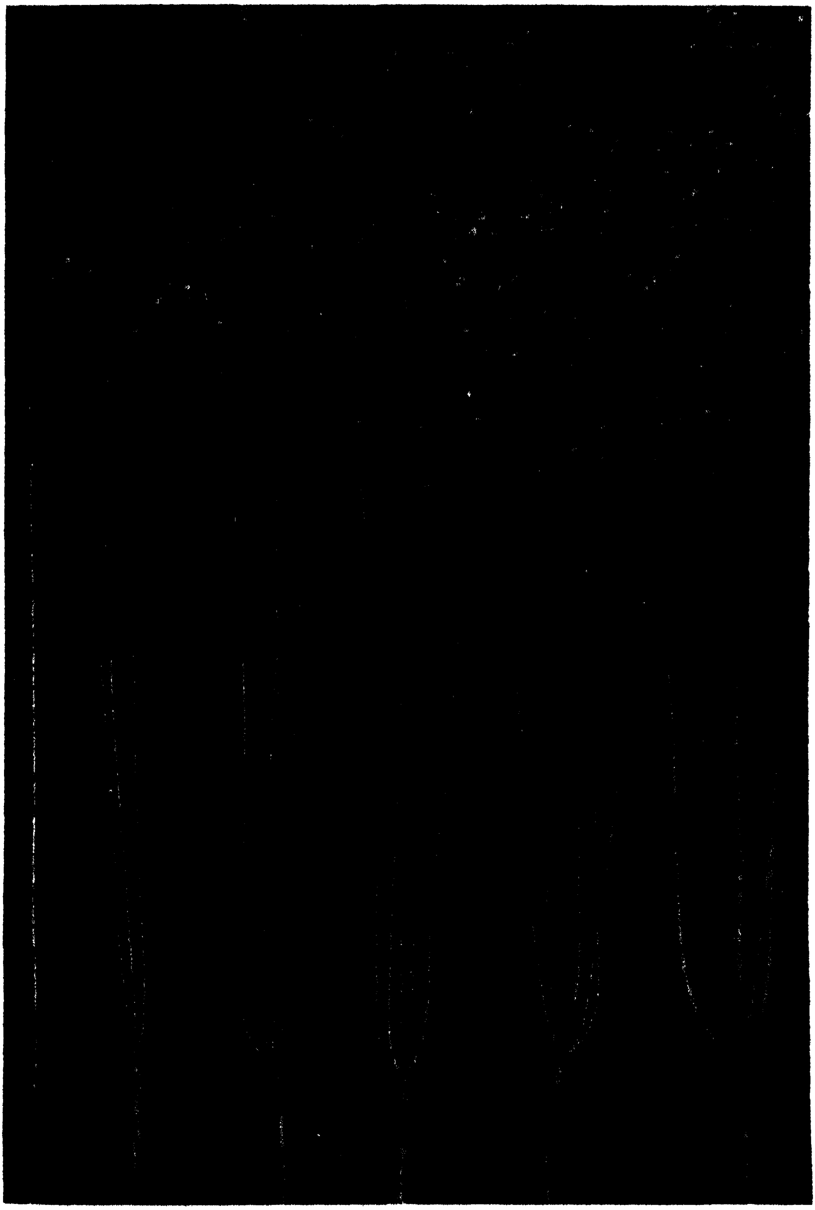

FIG. 2.—Typical plants of Rio flax grown at Mandan, N. D., in 1928. The plant at left in close stand, the others (left to right) spaced 1, 2, 3, 4, and 6 inches apart, respectively, in rows 1 foot apart. Linota plants showed similar characteristics of branching. (Photograph by J. C. Thysell.)

given. It is recognized that the computed yields are subject to error, because of the limited number of plants observed. The yields, however, are within the range of actual yields obtained in other varietal experiments during the same years. This was primarily a study of plant development, not a yield test.

The oil content of the seed and the iodine number of the expressed oils of each variety increased more or less uniformly from the close spacing to the 4- and 6-inch spacings. As found in numerous other experiments, the oil content is correlated with the weight of 1,000 seeds. Both the size of seeds and the oil content are determined in part by the quantity of soil moisture available to the plant. This is seen in comparing the data of 1928, when the seasonal rainfall was favorable, with 1929, a dry season.

The data show that every vegetative character of the plant is influenced by the space available for plant development. In making plant selections, therefore, the flax breeder should consider the importance of spacing in relation to the height, diameter of stem, number of basal branches, number of bolls, and yield of seed. With plants spaced either 2 or 3 inches apart, in rows 1 foot apart, the vegetative characters of individual plants can be observed and compared, and the yield of seed per plant is adequate for planting in short rows for further increase.

The data indicate also that the use of vegetative characters in the classification of flax varieties must be used with caution unless the varieties are grown under identical methods of spacing and identical soil and moisture conditions.

NATURAL CROSSING IN FLAX[1]

A. C. DILLMAN[2]

IN a study of the classification of flax varieties, the writer has observed considerable variations in the uniformity, from year to year, of single line selections of distinct flower types. In many cases the mixtures that occurred obviously were the result of natural crossing. This suggested a study of the extent of natural crossing among varieties of flax of distinct flower types, in which hybrids could be recognized readily. The results of this study, together with some observations on the time of pollination and fertilization in flax, are reported here.

The literature on natural crossing in flax has been reviewed by Henry and Tu (2)[3] and by Robinson (5) and will not be repeated here. The extent of natural crossing reported has ranged from 0 to 5% or more.

THE FLAX FLOWER

Four quite distinct forms of flowers (Fig. 1) occur in varieties of cultivated flax, *viz.*, (a) the common funnelform flower, as in Redwing, Bison, and Punjab; (b) the disk-shaped flower with large, flat petals as in Malabrigo, Rio, and Cyprus; (c) the star-shaped flower with narrow in-rolled or involute petals as in Tammes' "Crimped White"; and (d) the tubular flower found in two strains of Indian flax, C. I.

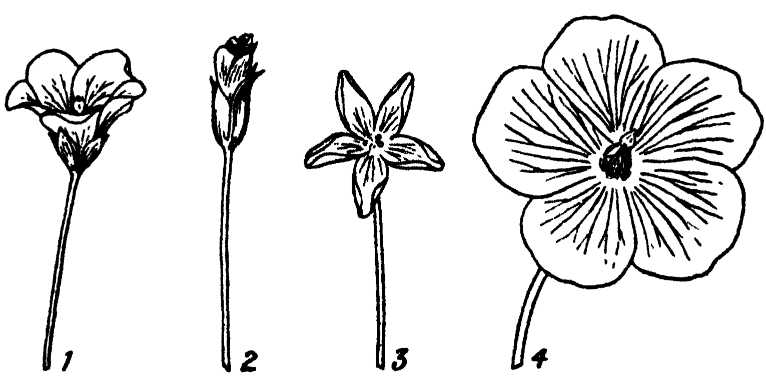

FIG. 1.—Flax flowers of the four principal types. (1) The common or funnelform; (2) tubular; (3) star-shaped or "crimped-white"; and (4) the large disk-shaped.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication January 10, 1938.

[2]Associate Agronomist. The experiments at St. Paul, Minn., and Bozeman, Mont., were conducted in cooperation with the state agricultural experiment stations. The author is indebted to A. C. Arny and to J. C. Brinsmade, Jr., for assistance in taking notes at St. Paul and at Mandan, respectively, and for reading the manuscript.

[3]Figures in parenthesis refer to "Literature Cited," p. 286.

156,[4] and Type 68 of Howard and Kahn (3). Somewhat intermediate forms also are found among the numerous varieties of cultivated flax.

The tubular flower is very unusual. The petals ordinarily remain rolled in the form of a tube open slightly at the tip. This is caused, according to observations of the writer, by the firm thick sepals which prevent the petals from spreading. If one or two sepals are spread slightly with a needle point, the petals open at once like a funnelform flower. However, in the humid atmosphere of the greenhouse the turgid petals exert sufficient pressure to separate the sepals and permit the flower to open. In a dry atmosphere the flowers remain tubular and the petals wither without dropping off. In this condition the dry petals form a closed sack, covering the stigma which lessens the chance of cross pollination and also protects the style and anthers from the drying effect of hot winds. Because of its shape, there is little natural crossing in the tubular flowers.

In the typical flax flower of most varieties the anthers entirely surround and over-top the stigma. In some varieties, however, the tip of the stigma is likely to be exserted slightly above the anthers, and thus is exposed to possible cross-pollination. This condition occurs most often in the large, disk-shaped flowers, especially in dry, hot weather, which probably accounts for the greater frequency of natural crossing often observed in varieties of this type. Many wild species of *Linum* are heterostyled and possibly a factor for this condition (length of filaments) exists in cultivated flax.

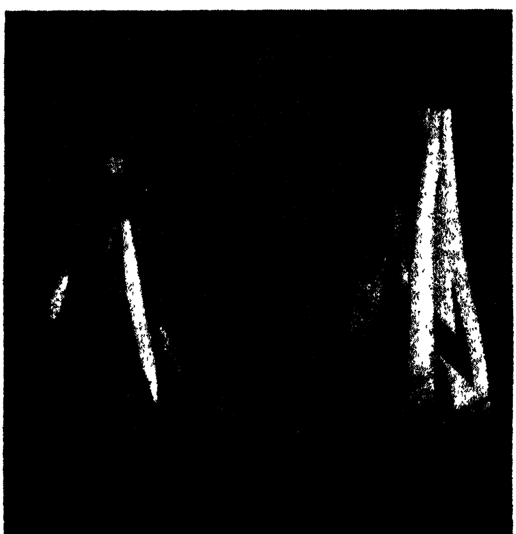

FIG. 2.—Flax flowers with sepals cut away and petals removed to show the inner parts. The flower at left, an F_1 hybrid of *crepitans* (dehiscent) × Indian Type 46, had short filaments and was nearly self sterile when grown in the greenhouse. At right, a flower of normal type with anthers completely surrounding and overtopping the stigma, thus assuring self pollination. × 8.

In crosses of Indian Type 46 (3) by two strains of dehiscent flax (var. *crepitans*), C. I. 759 from Ukraine and C. I. 760 from Germany (1), the F_1 generation had flowers with short stamens (filaments) and was almost self-sterile when grown in the greenhouse (Fig. 2). The flowers, however, were quite normal when grown in the field at Bozeman in 1937.

[4] C. I. refers to accession number of the Division of Cereal Crops and Diseases.

In rare cases the anthers are partly or wholly deficient in pollen. Such flowers usually remain open all day and thus are more exposed to outcrossing than the normal flower. In a cross of Bison × (Argentine, C. I. 160 × Winona), 3.3% of plants with deficient anthers were found in the progeny of an F_2 plant selection. A panicle of such a plant (1 of 20 found in a plat of 600 plants) is shown in Fig. 3.

TIME OF POLLINATION

The flower bud of flax opens at sunrise on clear, warm days and pollination occurs at once. On cool, cloudy days, however, the flowers open much later, or, in rare cases, the buds open only partly the first day and reopen fully the following day (3). The writer has made numerous observations on the time of opening of flax flowers. At St. Paul, Minn., on June 27, 1926, 10 buds each of N.D.R. 114 and Rio (Argentine) were observed. The sun rose at 4:26; the temperature at 5 o'clock was 54°, at 7 o'clock, 60°, at 9 o'clock, 68°, and at noon, 80° F. On all buds of both varieties the petals began to spread at 4:45; the flowers were partly open and the anthers dehisced at 4:50 to 5:15; the flowers were fully open (funnelform) at 6:40 to 7 o'clock; and the petals dropped off between 10:30 a.m. and noon.

FIG. 3.—A plant (A) with deficient anthers found in a cross of Bison × (Argentine × Winona). A normal plant (B) is shown at right.

At San Antonio, Texas, 12 buds of N.D.R. 114 were observed on April 25, 1926. The day was cool and partly cloudy; the minimum temperature was 56°, the maximum 73° F; the sun rose at 5:58. The buds began to open at 6:30; the anthers were visible and dehiscing at 6:30 to 7:15; the flowers were fully open (funnelform) at 9 o'clock; and the petals fell between 11:30 and 1:15.

Observations were made on 20 flowers of each of three varieties at Bozeman, Mont., July 22, 1928. The flower buds were tagged with woolen yarn the previous evening. The sun rose at 5:30; the day was clear; the temperature was 50° F at 5 a.m., 57° at 6, 68° at 8, 78° at noon, and 85° at 3 p.m. The observations are recorded in Table 1.

TABLE 1.—*Progress of blooming of 20 flowers of each of three varieties of flax at Bozeman, Mont., July 22, 1928.*

Variety	Anthers dehisced			Flower fully open			Petals fallen		
	Earliest	Latest	Av.	Earliest	Latest	Av.	Earliest	Latest	Av.
Novelty, C. I. 140	6:10	6:35	6:18	7:10	7:30	7:21	11:50	4:10	2:10
Argentine, C. I. 472	6:00	6:30	6:12	7:30	8:00	7:37	11:00	4:00	1:50
Indian Type 41	6:20	7:25	6:43	7:40	8:20	7:52	11:50	5:00	2:32

FERTILIZATION

Fertilization of the ovules takes place within a few hours after pollination as determined by rather crude experiments conducted in the field. In a preliminary experiment conducted at St. Paul, July 28, 1926, the pistils of a number of flowers were cut off with dissecting scissors at a point just below the stigma. When this was done at 8:10 a.m., some 3 hours after pollination, the bolls developed normally, indicating that fertilization had occurred, or, at least that the pollen tubes had penetrated the style before the stigmas were removed. On the same day, the styles of other flowers were cut off close to the ovary or boll (Fig. 4). This was done at 8:10 a.m. and again at 1:20 p.m. In flowers clipped at 8:10 no further growth of the bolls occurred; whereas, in flowers clipped at 1:20 the bolls developed in a normal manner, indicating that fertilization had occurred before 1:20. The normal development of the seeds indicated, also, that there was no serious injury to the boll (ovary) by this treatment.

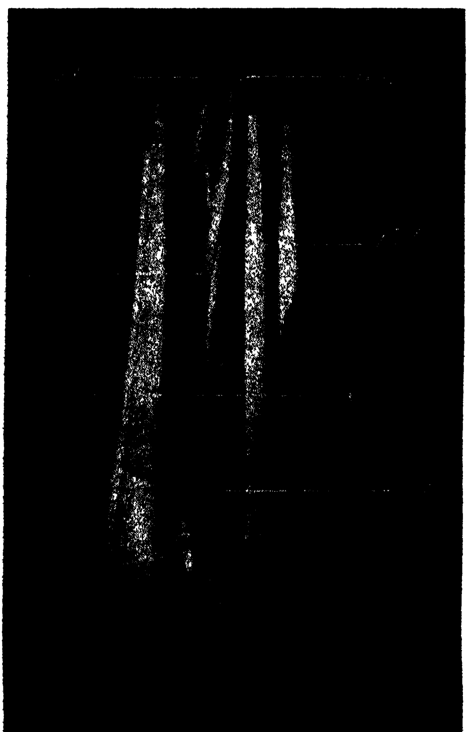

FIG. 4.—Inner parts of flax flower showing the dehiscent anthers (*an*), filaments (*fil*), boll or ovary (*ov*), style (*sty*), and stigma (*st*). To determine approximately the time of fertilization, the style and filaments were cut off at the line *X*.

The experiments were repeated at the Agricultural Experiment Station, Bozeman, Montana. In these experiments the pistils were cut off close to the boll as shown in Fig. 4. In flowers clipped at 7:30 and at 9:30,

Aug. 5, 1926, the bolls did not develop; whereas, those clipped at 11:30 a.m. and at 1:30 p.m. developed normal bolls.

On July 22, 1928, the styles of 10 flowers were clipped close to the boll, as shown in Fig. 4, at 9:15, at 10:30, and 11:45 a.m. All bolls developed and the number of seeds in each was as follows:

Boll No.	Number of seeds developed per boll when pistils were cut off at hour indicated		
	9:15 a. m.	10:30 a. m.	11:45 a. m.
1	6	8	10
2	2	8	10
3	1	9	10
4	8	9	7
5	8	9	10
6	5	8	7
7	7	10	9
8	9	5	8
9	10	10	5
10	3	8	9
Average	5.9	8.5	8.5

The results indicate that fertilization was incomplete in bolls 2, 3, and 10, clipped at 9:15, as only one to three seeds developed in each boll. Pollination had occurred at about 6:15, some three hours before the styles were cut off. In flowers clipped at 10:30 and at 11:45 a normal number of seeds developed, indicating that fertilization had occurred before 10:30 a.m. The normal development of the seeds indicated, again, that there was no injury to the boll by this treatment.

NATURAL CROSSING AMONG VARIETIES

In order to determine the extent of natural crossing in flax seven varieties were chosen that were distinct in shape of flower and in color of petals and other flower parts, so that hybrids could be recognized readily. The varieties were as follows:

1. Blanc (C. I. 323-3).—Flower saucer-shaped; petals large, white; anthers blue, filaments white; style white; bolls semidehiscent; seeds brown, large; plant short, early to midseason.

2. Indian Type 68 of Howard and Kahn (3).—Flower tubular; petals blue; anthers blue, filaments trace of blue; style light blue at base; bolls indehiscent; seeds brown, midsize; plant very short, early to midseason.

3. Pale Malabrigo (C. I. 690).—Flower large, saucer-shaped; petals large, pale blue or "Verbena Violet", Plate 37 of Ridgway (4); anthers blue, filaments white; style white; bolls indehiscent; seeds brown, large; plant stout, short to midheight, midseason.

4. "Crimped White" (C. I. 392).—Flower funnelform; petals white, narrow, separate, inrolled at margins; anthers yellow, filaments white; style white; bolls semidehiscent; seeds greenish-yellow, small; plant midheight, early to midseason.

5. Tall Pink (C. I. 451–3).—Flower funnelform; petals pink; anthers yellow; filaments pale blue; style trace of blue; bolls semidehiscent; seeds "dresden brown" (Plate 15, Ridgway), small; plant tall, midseason to late.

6. Ottawa 770B (C. I. 355).—Flower similar to "Crimped White" but slightly larger; petals white, narrow, separate, inrolled at margins; anthers yellow, filaments white; style white; bolls semidehiscent; seeds yellow, midsize; plant midheight, midseason to late.

7. Bison (C. I. 389).—Flower funnelform; petals deep blue or "Wistaria blue" (Plate 23, Ridgway); anthers blue; filaments about 1/3 light blue; style 1/3 blue; bolls semidehiscent; seeds brown, midsize; plant midheight, midseason.

In the blue-flowered varieties, Bison, Indian Type 68, and Pale Malabrigo, the petals have veins of a deeper shade than the "intervenia", the space between the veins. In Tall Pink the veins are light violet. In varieties with broad white petals and blue anthers, like Blanc, the veins are colorless, and in crosses with blue-flowered varieties the petals in the F_1 generation are light blue *without veins*, that is, the veins are the same color as the intervenia. Such hybrids are easily recognized. The petals of "Crimped White" and Ottawa 770 B also are white, *without veins*, but in crosses with blue the F_1 has veins.

The natural crossing experiments were conducted at University Farm, St. Paul, Minn., and at the Northern Great Plains Field Station, Mandan, N. D., in the three seasons, 1931 to 1933. Each variety was planted in a single row alternating with a single row of Bison and the plat bordered with two rows of Bison. The rows were 18 feet long and 1 foot apart. The planting was a part of a large flax nursery and, therefore, exposed to possible natural crossing with many varieties and strains.

The seed used in 1931 was obtained from the flax nursery grown at Bozeman, Mont., in 1930. The rows of each variety were rogued and the seed for planting examined carefully to make sure that it was pure. The hybrids found in 1931, therefore, should represent the natural crossing that occurred at Bozeman in 1930 Seed from each row, including Bison, was harvested carefully in 1931 and planted in 1932 and the same process repeated for the planting of 1933. Seed from all supposedly hybrid plants was sown the year after the plants were found to determine if they segregated and thus verify their hybrid condition. The results are reported in Table 2.

DISCUSSION

As had been observed previously, the greatest percentage of natural crossing occurred in the large-flowered varieties, Blanc and Pale Malabrigo, and very much less in the tubular-flowered variety, Indian Type 68. On the average, about 1.9% of natural crosses was observed in Blanc and only 0.3% in Indian Type 68. A maximum of 5% occurred in Blanc at Mandan in 1932, and 1% in Type 68 at St. Paul in 1932.

It is noteworthy that no natural crossing was observed in more than 8,000 plants of Bison flax grown during the three seasons. It is possible, of course, that hybrids of Bison by common blue were over-

TABLE 2.—*Natural crossing in seven varieties of flax grown at St. Paul, Minn. and Mandan, N. D., 1931–33.*

Variety	Total number of plants examined and number of hybrids found*											
	St. Paul						Mandan					
	1931		1932		1933		1931		1932		1933	
	Total	Hybrid	Total	Hybrid	Total	Hybrid	Total	Hybrid	Total	Hybrid	Total	Hybrid
Blanc	222	1	252	5	224	3	300	3	458	23	400	6
Indian Type 68	207	0	190	2	270	0	300	1	419	1	400	1
Pale Malabrigo	205	3	228	6	80	2	300	1	460	7	400	3
Crimped White	315	0	462	8	154	0	300	0	530	8	400	2
Tall Pink	223	0	493	0	238	2	300	0	428	8	400	1
Ottawa 770B	246	0	132	3	52	1	300	0	340	8	400	0
Bison	1,000	0	1,500	0	1,000	0	1,500	0	2,000	0	2,000	0

Variety	Percentage of natural crossing								
	St. Paul				Mandan				General average
	1931	1932	1933	Av.	1931	1932	1933	Av.	
Blanc	0.45	1.98	1.34	1.26	1.00	5.02	1.50	2.51	1.88
Indian Type 68	0.00	1.05	0.00	0.35	0.33	0.24	0.25	0.27	0.31
Pale Malabrigo	1.46	2.63	2.50	2.20	0.33	1.52	0.75	0.87	1.53
Crimped White	0.00	1.73	0.00	0.58	0.00	1.51	0.50	0.67	0.62
Tall Pink	0.00	0.00	0.84	0.28	0.00	1.87	0.25	0.71	0.49
Ottawa 770B	0.00	2.27	1.92	1.40	0.00	2.35	0.00	0.78	1.09
Bison	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*The results in 1931 represent the natural crossing that occurred at Bozeman, Mont., in 1930, where the seed was grown in a nursery of 200 or more varieties and strains. At Mandan the total number of plants grown in 1931 and 1933 were estimated; in all other cases the number were counted.

looked, as the F_1 plants would be difficult to recognize. It is certain, however, that the Bison variety is still remarkably pure after 15 years of cropping since its introduction. The anthers of the Bison flower entirely surround the stigma and pollen is so abundant that self-pollination is almost assured.

The results indicate that the percentage of natural crossing in flax differs in different varieties and in different seasons. The kind and abundance of insects probably determine chiefly the extent of crossing in varieties which, for any reason, are not completely self-pollinated. Thrips are nearly always present on flax flowers, but it seems doubtful if they are important in causing cross-pollination in flax, as suggested by Henry and Tu (2). They usually are present on bagged flowers as well as on those left uncovered. Honey bees and bumble bees often visit flax flowers and may carry pollen from plant to plant. There is also the possibility that the pollen may be blown short distances when it dries and falls from the anthers.

In selecting new varieties, perhaps the flax breeder should consider the type of flower with regard to abundance of pollen and the manner in which the anthers surround and over-top the stigma. A type of flower such as is found in Bison flax will assure a high degree of self-pollination.

The observations on the time of pollination and the simple experiments on the time of fertilization indicate that when normal pollination occurs there is little chance for outcrossing to occur. It is probable that outcrossing can occur only when there is some deficiency of anthers or pollen, or when the stigma is exserted beyond the anthers, or when hot, dry weather injures the pollen. The writer has considerable data to show that such varieties as Bison, Linota, and Redwing have a higher degree of fertility (more seeds per boll) in hot, dry weather than the large-flowered varieties such as Rio, Walsh, and others of this type. This is probably because the pollen and stigma of the larger flower is more exposed to the drying effect of sun and wind than is the smaller funnelform flower. It is notable, also, that the tubular flower of Indian Type 68 is remarkably self-fertile under such adverse weather conditions.

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BREEDING RYE BY CONTINUOUS SELECTION[1]

HOWARD B. SPRAGUE[2]

ALTHOUGH satisfactory breeding systems have been devised for crops that are largely cross-pollinated, such as corn, and those that are largely self-pollinated, such as wheat, oats, barley, etc., there is considerable divergence of opinion as to the most satisfactory method of breeding for the improvement of partly cross-pollinated crops. In fact, reliable estimates as to the degree of cross-pollination are wanting for most crops falling in the latter group. Obviously, it is necessary to have some approximate values on the amount of natural crossing and the consequent degree of heterozygosity in order that breeding systems may be given the proper theoretical treatment from the standpoint of genetics.

Rye (*Secale cereale*) is listed by Hayes and Garber[3] as a naturally cross-pollinated plant. Quoting various investigators, rye flowers are reported to be so constructed that it is difficult, if not actually impossible, for the pollen to fall on stigma of the same flower. Evidence is also given supporting the view that "the rye flower is self-sterile, but that the spikelet is not necessarily so". Heribert-Nilsson using a waxless type of rye plant as an indicator, observed cross-pollination to the extent of 37.3% to 54.4% when separated 60 meters from fields of normal plants. Other evidence is cited to indicate that self-fertilized florets are capable of producing seed, at least in some strains.

In view of the modern conception of the genetic causes of self-sterility in cross-pollinated species, it seemed worthwhile to re-investigate the extent to which cross-pollination occurs in other strains of rye than those used by European workers. A preliminary study indicated that, although self-pollination of florets might occur to a considerable degree with normal plants, pollen from other plants must account for a considerable part of fertilized flowers, even though the capacity for self-fertility prevails. The possibility of crossing between flowers of the same spike, or between flowers of different spikes on the same plant, which are genetically identical with self-pollination, also seemed to indicate the possibility of an appreciable amount of selfing with this crop.

On the basis of a substantial degree of self-pollination, continuous selection of superior plants in open-pollinated lines should gradually concentrate the genetic factors responsible for higher yields and permit gradual elimination of non-adaptive traits. This process should be more rapid when crossing is limited to strains of equal duration in the breeding nursery. In view of the continuous outcrossing, there would

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[2]Agronomist.

[3]HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. Ed. 2, New York: McGraw-Hill Book Co. 1927.

seem to be a much smaller chance of losing any favorable genes by segregation and elimination than might be expected for a breeding system in which inbreeding and development of stable lines plays an important part. Since no hand pollinations are involved in the program of continuous selection in open-pollinated lines, a large number of strains may be carried without undue expense or labor. In addition it may be assumed that superior strains developed by this method could be recombined at any stage in the breeding program without appreciable loss of yielding ability in the subsequent generations. Thus, the improved new variety could be maintained by the ordinary procedures to prevent mixing or hybridization with other strains.

SELECTION AT NEW JERSEY

The possibilities of rather rapid improvement by the time-honored methods of selection influenced the choice of this means of rye breeding at New Jersey. In order that the genetic constitution of the original stocks be as varied as possible, the following varieties were combined at the beginning of the program: Rosen (Michigan), Wisconsin Pedigree No. 2 (Wisconsin), Swedish (Minnesota), Abruzzi (Virginia), common (New York), and five sources of common rye from different portions of New Jersey. After two years, a total of 216 superior plants was chosen from a space-planted plat and these were treated as individual strains beginning with the nursery planted in September 1927. Each strain was space planted, 3 to 4 inches between plants, in rows 1 foot apart and 16 feet long. At maturity, one to two erect plants in each line which appeared to be more productive of grain and straw than others in that row were chosen to propagate the next generation. Selections were made annually by the writer to insure continuity in types chosen. Preference was given to outstanding plants with no better than equal opportunity in space and position. Care was taken in placement of the breeding nursery each year to obviate the possibility of cross-pollination by unselected rye.

In addition to the breeding nursery each selection was tested for yielding ability, using the seed remnant not required for space planting. In view of the limited seed supply, yield test plats were necessarily small and no replication was possible. Each strain was tested in an 8-foot row, with rows 1 foot apart. Every sixth row was planted to New Jersey common rye. The seeding rate of all selections was 6 pecks per acre. Yield tests of the entire nursery of 216 strains were harvested in 1929 for the first time and have been continued annually through 1937. For comparisons, all yields were calculated in percentage of the nearest check plats.

OBSERVATIONS ON DEGREE OF CROSS-POLLINATION

In view of the special significance attached to the amount of crossing in this system of breeding, a test was made in the season of 1930–1931, using Wisconsin Pedigree No. 6 rye which is practically pure for colorless kernels, and Rosen rye with greenish purple kernel color. A block of 10 rows of Wisconsin Pedigree No. 6 (Imperial) was planted with the rows 20 feet long and 1 foot apart. A similar block

of 10 rows of Rosen rye was planted on one side of the Wisconsin Pedigree plat. At harvest time, each row of Wisconsin Pedigree was harvested and threshed separately and the percentage of kernels showing the effect of pollination with Rosen rye determined. A similar test was conducted in 1936–37. The planting plan is given in Fig. 1 and the results are shown in Table 1.

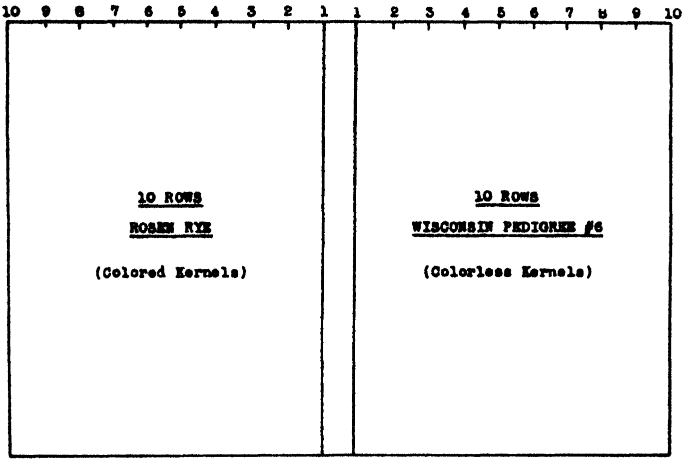

FIG. 1.—Planting plan to test the percentage of natural cross-pollination in rye as measured by xenia. The rows were 20 feet long and 1 foot apart; seeded at 6-peck rate in late September.

TABLE 1.—*Percentage of cross-pollination between Wisconsin Pedigree No. 6 White Rye (♀) and Rosen colored rye (♂), as measured by xenia, New Brunswick, New Jersey.**

Distance of White Rye from Rosen, feet	Cross pollination, %			Total crossing from both directions %
	Season of 1931	Season of 1937	Average	
1	29.9	20.3	25.1	50.2
2	24.2	15.8	20.0	40.0
3	21.1	12.3	16.7	33.4
4	17.4	9.7	13.5	27.0
5	9.1	7.7	8.4	16.8
6	7.2	6.7	6.9	13.8
7	7.6	6.9	7.2	14.4
8	8.2	6.4	7.3	14.6
9	4.8	6.9	5.8	11.6
10	3.7	4.5	4.1	8.2

*Rows planted in a Northwest to Southeast direction.

It is clear that in contiguous rows, cross-pollination, as measured by xenia, did not greatly exceed 50% in these tests. No account has been taken of the amount of foreign pollen provided by plants in the same row, but it seems unlikely that this would greatly increase the total. Xenia decreased at a rather uniform rate with increasing distance, reaching the low value of 8% at 10 feet. Doubtless pollen would

be carried by wind for much greater distances across open areas and in regions with strong winds at time of pollination. The average wind velocity in May and June at New Brunswick is approximately 10 miles per hour, with considerable variation from hour to hour and day to day. In a breeding nursery, the distance traveled should approximate that found in these tests.

Using 50% as the normal amount of cross-pollination occurring in the breeding nursery, the choice of a single plant accounts for three-quarters of the total inheritance, one-half coming through the female gametes of the mother plant and one-quarter from the male gametes of the same plant. Since outcrossing apparently accounts for one-quarter of the total inheritance, there is opportunity for a constant infusion of "new blood" from the other selected strains in the nursery. Improvement would be accomplished by gradually raising the productivity of the entire breeding nursery, but the possibility exists of obtaining superior blocks or groups of strains, since the bulk of the foreign pollen comes from distances no greater than 10 feet.

STABILITY OF A RECONSTITUTED VARIETY

In 1933, 98 strains were chosen as superior on the basis of yield tests conducted in 1931–32 and 1932–33. Since the seed remnants used in planting the above tests were inadequate for the purpose, seed from selected plants of the same strains in the 1933 crop were bulked and planted in an isolated field for increase in 1933–34 and 1934–35. With the seed so provided, the new variety was released for further testing in 1935–36 and 1936–37 under the name of "Raritan" rye.

It should be noted that the average yield of these 98 strains for the two years of individual yield tests was 130.4% of the unselected common rye. Raritan rye has since been found to exceed common rye by about 10%. This figure is of the same order as the average yield of all 216 strains for 1932 and 1933 and not that of the 98 selections. Apparently no superiority of individual lines had yet been established when the 98 selections were chosen and the new variety merely represented the increased vigor of the entire nursery.

One of the prime considerations was the determination of the stability of the new variety. In 1936, trials were conducted with the original blended seed from the 1933 crop and seed of the two subsequent generations. Each seed lot was grown in nine plats in comparison with common rye, using the seeding rate of 6 pecks per acre. The individual plats were 12 feet long and 3 feet wide. The germination had dropped to 78% on the 1933 seed lot, and to compensate for this a heavier seeding rate was used. The yields of grain and straw for the three different generations of Raritan rye are shown in comparison with common rye in Table 2. Although the first generation seems somewhat superior to the parental blend and to the second generation, such behavior may be explained by chance fluctuations and by incomplete compensation for the low germination of the oldest seed lot.

A further test of the stability of Raritan rye is provided by the regular yield tests in comparison with New Jersey common and Rosen, the results of which are given in Table 3. The varietal tests

TABLE 2.—*The stability of a new rye variety created by combining 97 related selections as measured by growth tests in the year 1935–36.**

Generation	Average height of plant, in.	Straw yield per acre, lbs.	Grain yield per acre, bu.
Raritan rye:			
1933 seed, parental blend of 97 strains....................	54.3	5,370	46.0
1st generation, 1934 seed	54.6	5,892	50.1
2nd generation, 1935 seed......	53.9	5,773	48.8
Common unselected rye	53.4	5,328	45.6

*Average of nine plats per seed lot; seeding rate adjusted to provide 6 pecks per acre of seed germinating 90%. 1933 seed germinated 78% when seeded in September 1935.

TABLE 3.—*Performance of Raritan rye from the second to fourth year after its creation by combination of 97 related selections.*

Variety	Straw yield per acre, lbs.*				Grain yield per acre, bu.*			
	1935	1936	1937	3-year average	1935	1936	1937	3-year average
Rosen................	6,873	5,208	3,869	5,317	55.1	48.1	27.7	43.6
N. J. common	7,481	5,987	3,841	5,770	52.9	52.0	25.0	43.3
Raritan	7,545	6,484	4,161	6,063	57.9	55.6	30.9	48.1
Increase of Raritan over N. J. common, %	0.9	8.3	8.3	5.1	9.4	6.9	23.6	11.1

*Average of 10 nursery plats per variety, plats 16 feet long and 36 inches (five drill rows) wide trimmed at harvest to 12 feet by 21 inches.

were planted with a grain drill in rows approximately 7 inches apart, at a 6-peck rate. Each variety appeared in 10 systematically distributed plats, 16 feet long and 36 inches (five drill rows) wide. The plats were trimmed at harvest time to 12 feet by 21 inches (three drill rows). The 1935 comparison indicates the yielding ability of the first generation after combination of the 98 lines, 1936 the second, and 1937 the third generation.

These three tests support the assumption that lines produced by continuous selection of outstanding plants with open-pollination are comparatively stable when combined. The fluctuations in relative yields of Raritan indicate no recession in vigor or adaptation; merely the differential response of the new variety to changes in the environment.

PROGRESSIVE CHANGES IN VIGOR OF STRAINS

It was recognized that Raritan rye had been produced after a comparatively short period of selection. To test whether any further increase in vigor might have resulted from continued selection, the yields of individual strains for the crop years ending in 1935, 1936, and 1937 were examined. Eliminating from consideration all strains which had failed to be consistently high in grain yield during the

3-year period and which had failed to average 20% or more grain than the unselected check variety, a total of 95 strains remained. The average increase in yield of these strains for the 3-year period was 44.7% in contrast with 30.4% increase for the most productive 98 strains in the test period four years earlier. An important point is that 57 selections are found in both groups, supporting the belief that this breeding method permits the development of superior blocks or groups of strains because of the rather limited horizontal distribution of pollen.

Some further evidence on progressive changes in yielding ability of the breeding nursery is provided by the average yield of all 216 strains for the years 1932 and 1933 in contrast with the years 1935–37, inclusive (Table 4). Using averages to compensate for annual fluctuations, it seems probable that the difference between 112.4% for the first period is significantly lower than that of 130.6% for the latter period. An additional test of this breeding method will be provided during the next three years by the performance of the new variety produced by combining 1937 seed of the 95 strains which showed superiority from 1935 to 1937.

TABLE 4.—*Average grain yield of 216 rye selections in terms of unselected common rye.*

Year grown	Percentage yield of 216 selections	Grain yield of unselected common rye, bu.
1932	97.9	27.6
1933	127.0	31.7
2 year av.	112.4	29.6
1935	111.7	52.9
1936	123.4	52.0
1937	156.7	25.0
3-year av	130.6	43.3

DISCUSSION

The evidence given by these tests supports the assumption that rye is a partly cross-pollinated species and that considerable general improvement may be achieved by continuous selection of superior plants with open pollination. The stability of a mass variety produced by combining a large number of lines similarly selected is significant from the standpoint of practical utilization of the breeding product. Although considerable time seems to be necessary to achieve outstanding superiority, the results suggest that the number of generations is no greater and perhaps less than would be required by the inbreeding and recombination system.

There are several limitations to this system of breeding. For species that approach complete cross-pollination, such selection should not be expected to produce any more favorable results than has been found for corn. It should also be observed that characters cannot be accu-

mulated or concentrated unless present in the breeding nursery. Consequently, there would be a great advantage in beginning the breeding nursery with a wide range of types and by including such specific characteristics as are known or suspected to be advantageous. Moreover, this method of breeding gives no information on the inheritance of specific characters or genes. Also, the final product, a commercial variety, will show much greater variability than one developed by inbreeding and isolation of purified lines.

To compensate for the limitations of this breeding method, there is the greater assurance that favorable factors will not be lost by segregation and elimination and that strains may be combined for commercial use without loss of vigor in subsequent generations. In addition, a large breeding nursery may be maintained with a relatively small amount of labor and personal attention. Plant breeders whose responsibilities cover a considerable number of species may be able to produce substantial improvement of partly cross-pollinated species without requiring a large staff of skilled assistants. It seems likely that many forage plants will fall in the category of partly cross-pollinated species, and thus be favorable objects for this system of improvement.

SUMMARY

Rye is apparently partly cross-pollinated to the extent of approximately 50%, judging by the amount of xenia evident in a colorless kerneled variety of rye growing adjacent to a colored kerneled variety. Less than 10% of the foreign pollen was effective at a distance of 10 feet under comparatively normal conditions.

A total of 216 strains were selected from a mass variety containing 10 varieties and strains after two years of natural crossing. Each of the 216 lines was continued from 1928 through 1937 by selection of superior plants in space-planted rows with open-pollination permitted between all lines in the breeding nursery. Parallel tests of yielding ability were made for all lines, using solid rows, with unselected common rye as the check.

After five years of selection, 98 lines were chosen for 1933–34 on the basis of yield performance during the previous two years, and these were combined to form a new variety named Raritan. Raritan proved to be stable in yielding ability in subsequent generations, exceeding common rye by 10% to 12% in grain yield.

Further improvement in productivity by continued selection within each of the 216 lines for the four years ending in 1937 is indicated by the yielding ability of the best 95 lines and by that of the entire breeding nursery.

The limitations and advantages of this system of breeding are briefly discussed. Gradual concentration of desirable traits, and elimination of non-adaptive characters is provided without danger of losing valuable genes as usually occurs with inbreeding. The system requires relatively little time and skilled aid, but furnishes no information on inheritance of specific factors.

EXPERIMENTS ON ARTIFICIAL HYBRIDIZATION OF RICE[1]

N. E. JODON[2]

RICE is an attractive crop for genetic studies, displaying fully as many variations as any other of the small grains. The scope of plant breeding and genetic investigation with rice might be enlarged if a rapid and effective method of controlled pollination were available. The hybridization technic described by Jones (5)[3] is widely used and sufficient hybrid seed may be obtained for the usual studies of segregating populations, but the seed set is too low for extensive back-crossing or studies requiring large numbers of crossed seeds.

REVIEW OF LITERATURE

BLOOMING

The literature on pollination and blooming in rice up to 1929 has been reviewed by Jones (6). Adair (1) made an extensive study on blooming in rice in Arkansas, and Laude and Stansel (7) made observations in Texas under conditions nearly identical with those under which the data here reported were obtained. The writer has tabulated no data on blooming but his general observations are, with some exceptions, in agreement with the results reported for Texas and Arkansas.

The peak of blooming at Crowley, La., in seasonable weather in August and early September when most varieties are at the blooming stage appears to occur between 10:00 and 11:00 a.m. rather than between 11:00 a.m. and noon as reported by Adair (1) and by Laude and Stansel (7). The departure from the behavior in Arkansas may be due to temperature differences. The difference from results obtained in Texas may be due to observing different varieties. Adair suggests that pollen may be shed before the florets open, but the writer's observations indicate that exposure to the open air is normally necessary for dehiscence of the anthers. Laude and Stansel stated that rice florets may remain open from 42 minutes to over 2 hours. The writer found that at Crowley the florets usually opened and closed within an hour or less.

Temperature, as suggested by Adair (1) and by Jones (6), probably is the most important factor influencing the time of blooming in rice. These workers noted differences among varieties in the time of initial daily blooming and the writer has observed differences of as much as 2 hours. No explanation of such varietal differences has been found in the literature, but the writer has observed that varieties having long slender glumes appear to bloom earliest. A slight swelling of the lodicule will open long narrow glumes to a sufficient angle to expose the anthers at the tip of the floret. Short and relatively wide glumes must be spread at a wider angle to expose the anthers, hence more time may be required for the lodicel to swell sufficiently to open the floret fully.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Louisiana Experiment Station. Experiments conducted at the Rice Experiment Station, Crowley, La. Received for publication December 30, 1937.

[2]Assistant agronomist.

[3]Figures in parenthesis refer to "Literature Cited," page 305.

ARTIFICIAL POLLINATION

The method of crossing used by Jones (5) in California, which will be referred to here as the clipping method, involves emasculation by removal of anthers with tweezers through a slanting opening made by clipping away a portion of the upper part of the lemma. This is done in the evening or morning prior to normal blooming and before the anthers have reached the stage where they will shed pollen on handling. When the clipping method was used in Louisiana, the crossed seeds were imperfectly developed and germination low.

Pollination is accomplished by breaking mature anthers within the emasculated floret. Mature anthers may be obtained from florets in which the elongating filaments have pushed the anthers towards the apex of the unopened glumes. Such anthers ripen rapidly after the glumes are forced open, changing from a dark yellow color and firm consistency to a lighter yellow color and a mealy texture as the pollen grains separate within the anther sack and burst readily on handling. This method of obtaining pollen was followed in making all crosses reported herein.

The application of collected pollen with a flattened needle as described by Florell (3) for wheat was unsuccessful because of the humid conditions in the rice field. Rice pollen appears to be viable for only a brief period. Mechanical stimulation as used by Florell to hasten anthesis of wheat for the collection of pollen was not effective in rice.

Van der Meulen (8) in Java applied to rice the suction method of emasculation developed by Kirk with satisfactory results by either clipping off part of the glume or by using early opening florets which had not shed pollen. In all varieties used in the studies by the writer at Crowley pollen was shed before the florets opened enough to permit removal of anthers, except when the temperature was unseasonably low.

Ramiah, as reported by Dumont (2), found that increasing the temperature artificially hastened the opening of the glumes. He reported that the heat absorbed by panicles covered with a black paper bag raised the temperature sufficiently to induce blooming. The anthers of such florets do not dehisce immediately and may be removed without injury to other parts of the floret. The writer, however, failed to obtain satisfactory opening of florets by this means under Louisiana conditions.

Poggendorff (10) also attempted the use of black paper bags to hasten opening but found that anthers often burst upon their removal from the florets. He found, however, that on humid days anthers may be removed from the naturally opening florets before dehiscence. Poggendorff obtained pollen from panicles floated on water, the temperature of which hastened the development of the anthers to the point where they burst on handling. He was "usually 100% successful" in obtaining crosses.

Mulimbayan (9) has compared the clipping method with a method in which mechanical stimulation was used to open the glumes, after which the anthers are removed without injury to the floret. The clipping method was more rapid and gave the better results, but anther sacks were sometimes clipped and the pollen scattered. This difficulty was not encountered in Louisiana.

A method of emasculating sorghum by means of heat was developed by Stephens and Quinby (12). A container was fitted around the sorghum head, filled with water at an initial temperature of 44° C, and allowed to remain 10 minutes. The viability of the pollen was destroyed without injury to other floral

organs. This method appeared to be adaptable to rice and the writer's results with it are reported herein.

Suneson (13) found anther sterility in wheat to be induced by temperatures of 27° to 36° F. Some or all florets opened on spikes emerging from the boot one to five weeks after exposure to temperatures within this range were self sterile. Self-sterile florets were easily distinguished since they remained open and cross pollinations were successful. The writer tested the effect of low temperatures on rice flowers in 1936.

PROCEDURE AND RESULTS

INJURY DUE TO MANIPULATION

An experiment was conducted to obtain information on the extent of injury caused by clipping and bagging rice florets in which the lemma, palea, or both, were clipped. The anthers were not removed. The method used by Jones (5) was followed in clipping the lemma. The smaller size and the relative position of the palea required the removal of a proportionately greater part of this organ in making an opening large enough to permit the insertion of tweezers. When both the lemma and palea were clipped, the cut was made in much the same way as when the lemma alone was clipped, but the angle of the cut was changed to include a part of the palea. The panicles were clipped or bagged early in the morning or in the late afternoon. From one-fourth to one-half the florets on the panicles used probably would have opened the day they were chosen or the following morning. Florets that had bloomed previously were removed. Some of the panicles were covered with glassine bags and others were left uncovered. Two rather dissimilar varieties, Fortuna and Early Prolific, were used. The results are summarized in Table 1.

There were no consistent differences in seed set following different methods of clipping when the panicles were bagged. The lowest set within Fortuna was obtained when the palea was clipped, but this did not occur in the Early Prolific variety.

The unbagged clipped panicles gave a lower seed set than did those that were bagged. This probably was due chiefly to extrusion and failure of dehiscence of the immature anthers and to desiccation of the stigma and palea. Exposure to insects and fungus organisms may also have been factors. The lowest seed set resulted from clipping the palea and nearly as much sterility followed clipping both glumes.

The results of clipping the lemma in the morning and late afternoon also are given in Table 1. While differences were found, they were not consistent since a lower seed set was obtained in Fortuna from afternoon and in Early Prolific from morning clipping.

Bagging alone, when done in the morning, reduced the seed set to about that of the bagged clipped panicles. Handling and increased temperature within the bag perhaps caused the florets to open prematurely, and be followed by extrusion and imperfect dehiscence of anthers with a resulting incomplete pollination. Bags placed on the panicles in the evening had less effect on the seed set. Fortuna panicles bagged in the evening gave practically a normal seed set, while Early Prolific showed some reduction.

TABLE 1.—*Effect of clipping glumes and bagging panicles on the percentage of seed set in Fortuna and Early Prolific rice.*

Organ clipped	Time	Panicles bagged: Panicles, No.	Florets, No.	Seed, No.	Set, %	Panicles not bagged: Panicles, No.	Florets, No.	Seed, No.	Set, %
				Fortuna					
Lemma . . .	A.M.	6	625	456	73.0	5	644	240	37.3
Lemma . .	P.M.	4	335	226	67.5	4	299	109	36.5
Palea* . . .	——	4	382	196	51.3	5	328	53	16.2
Both glumes*	——	4	338	220	65.1	5	437	85	19.5
None . . .	A.M.	5	944	644	68.2	5	959	816	85.1
None . . .	P.M.	4	820	700	85.5	4	806	712	88.3
				Early Prolific					
Lemma. .	A.M.	7	603	242	40.1	4	285†	31	10.9
Lemma	P.M.	4	313	175	55.9	6	435	135	31.0
Palea* . .	——	4	261	130	49.8	4	281	8	2.8
Both glumes*	——	4	258	145	56.2	4	246	16	6.5
None	A.M.	7	852	392	46.0	4	434†	383	88.2
None	P.M.	4	521	333	63.9	7	913	772	84.6

*1934 only, other data are combined results from 1934 and 1936.
†1936 only.

RELATION OF TEMPERATURES TO SEED SET

The success of Stephens and Quinby in the use of hot water for bulk emasculation of sorghum flowers suggested the possibility of adopting this method for rice. The application to rice was simple in contrast to the difficulty of fitting a water-tight container around the stalk below a head of sorghum. Rice culms were merely bent over and the panicles inserted in a small-mouthed quart-size thermos bottle. A trough-like holder for the thermos bottle, mounted on two spreading legs in front and a shorter one behind, was devised. The legs were pointed so that the holder could be set firmly in the mud at any angle necessary to permit immersion of the panicles without spilling the water.

All tests were made in the field. The temperatures used ranged from 50° C down to 0° C, and the duration of treatment varied from 2 to 25 minutes. The majority of the treatments were of about 10-minute durations. The first tests were made in 1934 and the results are shown in Table 2.

A valuable immediate result of the tests was the discovery that treatments made during the morning, prior to natural blooming, cause the florets to open in response to the stimulus of the sudden change of temperature. Opening takes place promptly except when the temperature of the water used was not more than 3 or 4 degrees above or below the air temperature. This prompt opening eliminates the necessity of clipping the glumes to get access to the anthers and stigma.

Panicles used were ordinarily about two-thirds exserted from the boot. At this stage the greatest number of florets are ready to bloom

TABLE 2.—*Effect of immersion of rice panicles in water at temperatures from 0° to 51° C on the viability of the pollen.*

Year	Treatment		Varieties, No.	Panicles			Florets opened, No.	Grains obtained, No.	Seed set, %
	Temperature, °C	Duration, min.		Treated, No.	Setting one or more grains, No.	Panicles, %			
1936–37	0° –3°	5–10	5	9	3	33.3	207	6	2.9
1937	4°	10	6	9	4	44.4	287	14	4.9
1936–37	5°	10–20	6	10	4	40.0	286	18	6.3
1936–37	6°	7–10	6	9	5	55.6	344	34	9.9
1936–37	8°	6–12	4	7	7	100.0	183	70	38.3
1936–37	9° –11°	6–13	3	6	6	100.0	195	145	74.4
1936	12° –19°	5–10	3	3	3	100.0	70	21	30.0
1936	20° –39°	10	3	12	12	100.0	351	219	62.4
1935	42° –44°	10–25	7	22	1	4.5	545	1	0.2
1936	40° –44°	10–12	5	20	0	0.0	521	0	0.0
1936	42° –44°	2–6	5	22	7	31.8	907	41	4.5
1936	43° –44°	10*	2	3	2	66.7	27	2	7.4
1937	43°	10*	1	1	1	100.0	17	14	82.4
1936	40° –42°	10†	5	12	10	83.3	158	95	60.1
1936	42° –44°	10†	5	11	5	45.5	122	5	4.1
1936	44° –46°	10†	1	2	2	100.0	8	4	50.0
1936	45° –47½°	10	2	9	0	0.0	161	0	0.0
1936	47½°–51°	10	3	10	0	0.0	0	0	0.0
1936	Check, not covered‡		2	11	11	100.0	1,692	1,549	91.5
1936	Check, covered‡		2	13	13	100.0	2,284	1,578	69.1

*Treated while florets were open and after anthers dehisced.
†Afternoon treatments; florets opened following morning.
‡Adapted from data in Table 1.

on a given day and consequently the greatest number opened in response to treatment. Mature florets which had bloomed previously and immature florets which did not open were removed and the panicles covered with glassine bags until after the glumes were closed. When treatments were made one to two hours prior to the beginning of natural blooming, opening sometimes began before the panicle was removed from the water. All florets which responded were usually beginning to open within a half hour after treatment. Varietal differences were observed in the time required for florets to open. Response was slow on cool mornings.

Temperatures of 47° C or higher resulted in the death of the entire panicle and of any portion of the flag leaf that also happened to be immersed in the hot water. Florets usually failed to open at this temperature. Anthers became watery in appearance and did not dehisce. Slight injury was indicated by bleaching of the chlorophyll at temperatures as low as 43½° C, while some panicles showed no appreciable injury at 45° C.

Panicles treated at various temperatures are shown in Fig. 1.

Within the temperature range of 40° to 44° florets opened promptly and normally. The anthers dehisced normally and the stigmas were usually dusted with pollen. It will be noted from Table 2 that from over 1,000 florets opening in response to treatments of 10 minutes or more at 40° to 44° only one seed was formed. Temperatures within this range are shown by these results to destroy the viability of the pollen effectively.

Florets on panicles treated in the afternoon at 40° to 44° did not open until the next morning. Nevertheless, opening took place earlier in the morning than normal blooming. Afternoon treatments at 42° to 44° destroyed the pollen more effectively than treatments at 40° to 42°. Most florets failed to open when treated at temperatures above 44°.

Treatments made at 43° to 44° approximately one-half hour after normal blooming had begun, after stigmas were well dusted with pollen and while the florets were still fully open, did not prevent fertilization of the ovary. This suggests that possibly the pollen had germinated and the male gametes had entered the pollen tube prior to treatment. Pope (11) reports that in barley pollen had germinated within 5 minutes after reaching the stigma and that within 10 minutes the male gametes had entered the pollen tube. Treatments made 24 hours after pollination were entirely without effect on seed set.

Low and intermediate temperatures were also tested. The percentage of seed set was low after treatment at temperatures of 0° to 8° C. Treatments at 0° to 3° C for 10 minutes probably would be effective for emasculation. No injury was noted, but the higher range for use in making crosses is preferred as the florets usually open somewhat more promptly.

Temperatures ranging from 9° to 39° C had little effect on the percentage of seed set. Collecting pollen in quantities for mass pollination from florets opened by temperature treatments not injurious to pollen does not appear feasible because the anthers from such florets do not

FIG. 1.—Pollen was unviable in rice florets that opened in upper part of panicles in response to high (40°–44½° C) and low (0°–4½° C) temperatures. Little or no other injury occurred at 44½° C or lower. Some seed developed following treatment at 39° C but not at 40° C.

dehisce readily and rice pollen becomes sticky and useless almost immediately upon exposure to moist air.

EFFECT OF METHOD OF EMASCULATION UPON SEED SET

The result of cross pollinations following emasculation by clipping and the hot and cold water methods are given in Table 3. Jones' method of obtaining and applying pollen was followed. Varieties differing in length of growing season were brought into flower simultaneously by planting on different dates, as suggested by Jenkins (4), or

TABLE 3.—*Comparison of artificial pollination of rice emasculated by three methods.*

Year	Method of emasculation	Varieties used, No.	Panicles total, No.	Setting one or more grains		Florets, No.	Seed set		Non-crosses, No.	F_1 plants matured, No.	Percentage F_1 plants matured on basis of	
				Number	%		Number	%			Florets pollinated	Supposedly crossed grains
1934	Clipping	21	159	113	71.1	1,458	379	26.0	26	208	14.3	54.9
1935	Clipping	14	38	20	52.6	390	72	18.5	5	19	4.9	26.4
1936	Clipping (includes all)	13	24	18	75.0	279	109	39.1	4	39	14.0	35.6
1935	Hot water (exclusive of backcross)	15	28	25	89.3	478	167	34.9	4	137	28.7	82.0
1936	Hot water (includes all)	24	73	67	91.8	1,347	572	42.5	5	403	29.9	70.5
1935	Hot water (backcross)	1	14	8	57.1	282	14	5.0	1	13	4.6	92.9
1936	Hot water (backcross)	1	8	8	100.0	340	141	41.5	0	133	39.1	94.3
1936	Clipping (glutinous) } Paired	4	5	5	100.0	56	31	55.4*	0†	14	25.0	45.1
1936	Hot water (glutinous) } Paired	4	5	5	100.0	71	52	73.2*	1†	20	28.2	38.5
1936	Clipping (non-glutinous) } Paired	7	10	6	60.0	112	31	27.7	0	13	11.6	41.9
1936	Hot water (non-glutinous) } Paired	7	10	10	100.0	110	56	50.9	0	49	44.5	87.5
1934–36	Clipping, total	36	221	151	68.3	2,127	560	26.3	35	266	12.5	47.5
1935–36	Hot water, total	35	115	100	87.0	2,107	753	35.7	10	553	26.2	73.4
1937	Hot water (includes all)	34	122	111	91.0	2,526	1,221	48.3	—	—	—	—
1937	Hot water } Paired	10	17	15	88.2	264	125	47.3	—	—	—	—
1937	Cold water } Paired	10	17	16	94.1	242	80	33.1	—	—	—	—

*Percentage crossed grains. †Iodine test.

by short-day treatments of late varieties. Attempts to develop more rapid methods of pollination failed.

An initial temperature of about 43½° to 44° C was used for the hot water treatments. The temperature was lowered during the 10-minute treatment about 0.5° C for each panicle immersed in the bottle. Thus three or even four panicles could be treated in the same water without cooling the water too much. This was the number ordinarily pollinated during one morning. Cold water emasculation was accomplished by 10-minute treatments at about 1° to 4° C. The results of the pollinations are given in Table 3, and pollinated panicles are shown in Fig. 2.

In 1935 the clipping method gave only 18.5% seed set, although if eight panicles lacking in vigor that failed to set seed are excluded the percentage becomes 23.2, while the hot water method gave a seed set of 34.9%.

In 1936 similar panicles were selected in pairs, emasculated by the clipping and hot water methods, and pollinated. The glutinous varieties were recorded separately since at Crowley they usually give a higher seed set than the non-glutinous varieties. A seed set of 55.4% was obtained by the clipping method and 73.2% by the hot water method in the glutinous varieties. With the non-glutinous varieties a 27.7% set was obtained by the clipping method and 50.9% by the hot water method. Comparing all pollinations made by the two methods in 1936, a difference of only 3.4% was found in favor of the hot water method. The paired panicles, however, probably give a truer comparison of the relative success of the methods because of the large proportion of glutinous panicles among those clipped.

Since the season did not appear to have any influence on the success of pollination, it may be noted that in 1934, when only the clipping method was used, a seed set of 26.0% was obtained, while in 1937 with the hot water method 48.3% of the florets set seed. Thus the hot water method would appear to be nearly twice as successful as the clipping method.

Hot and cold water treatments, the latter at about 2° to 4° C, were compared in 1937 by means of paired panicles. Hot water treatments gave a 47.3% set, while the cold water treatments resulted in only 33.1% set.

A distinct advantage of the hot water method is that the seeds obtained usually are fully developed, are protected by the glumes, and consequently germinate as well as ordinary seed. The low germination from the paired glutinous crosses (Table 3) probably was due to injury inflicted in making an iodine test of the endosperm to detect non-crosses. The percentage of F_1 plants obtained on the basis of florets pollinated as shown in Table 3 is usually distinctly higher for the hot water method. On the basis of supposedly crossed seeds for glutinous varieties the number of F_1 plants that matured ranges from 38.5 to 92.9% from the hot water method and from 26.4 to 54.9% from the clipping method. The number of F_1 plants matured from supposedly crossed seed obtained in 1934 to 1936, inclusive, by the clipping and hot water methods were 47.5 and 73.4%, and on the basis of florets pollinated 12.5 and 26.2%, respectively.

FIG. 2.—Seed set on rice panicles pollinated after emasculation by clipping and hot water methods. Florets on lower portion of panicle were not pollinated.

The crossed seed were germinated in the laboratory on saturated absorbent cotton.[4] The seed were usually treated with Ceresan immediately before placing them on the cotton. No nutrient solution was used. When the seedlings reached a height of 4 to 6 inches, they were transplanted in the field. The germination of seed obtained in 1936

[4]This procedure was suggested by J. Mitchell Jenkins, Associate Agronomist and Superintendent of the Rice Experiment Station, Crowley, La.

was higher than is indicated in Table 3 for a number of seedlings were lost largely because they were growing more slowly than the majority and were transplanted before they attained sufficient size.

An occasional self occurred among the supposedly crossed seed. These may have been due to incomplete removal of anthers, to failure of the temperature used to destroy pollen completely, to wind pollination before the bag was placed over the panicle, or to overlooking unopened florets following treatment. Non-crosses were easily detected, however, and were too few to be of importance. Non-crosses would be most easily overlooked, however, among backcrossed F_1 plants.

An illustration is included in Table 3 of the necessity of using mature anthers in pollination. In 1935 a backcross was attempted with the female parent plants growing in the field while the anthers were collected from F_1 plants growing in a large screened insect cage. Blooming of the F_1 plants was delayed about an hour due to a lower temperature in the shade of the cage, and pollen was probably not fully developed when used. The result was a seed set of only 5.0%, whereas in 1936, when F_1 plants were grown in the field and anthers matured early, a seed set of 41.5% was obtained.

In 1937 the use of glassine bags to protect panicles pollinated following hot water emasculation was practically discontinued. While bags afford protection from wind pollination and insects, they cause breakage of culms in the wind. Difficulty also arises from the panicles growing further out of the boot after pollination and crowding against the end of the bag. Since pollinations were made before normal blooming and the plants used were usually at least several feet from other varieties in flower, the danger of wind or insect pollination was not considered serious.

SUMMARY AND CONCLUSIONS

Three methods of emasculating rice florets were used successfully in the field and comparative results are given.

The clipping method necessitates the excision of a portion of the lemma and the removal of anthers by means of tweezers. In experiments in which glumes were clipped but anthers not removed, a reduction in seed set occurred. This was not entirely due to injury from clipping since exposure of the stigma and the immature anthers to the air probably interfered with normal pollination. The seed set was much less when the panicles were unprotected than when covered with glassine bags. When bagged there was no difference in the effect of clipping the lemma, palea, or both glumes. A greater reduction in seed set resulted from clipping in Early Prolific than in Fortuna. Covering uninjured panicles with glassine bags usually lowered the seed set, probably by interference with normal blooming.

The effect of temperatures from 0° to 50° C on emasculation was tested. The treatment was applied by immersing panicles in water contained in thermos bottles. Variations of a few degrees above or below the air temperature hastened opening of florets. When applied in the morning prior to normal blooming, 10-minute treatments at

40° to 44° C destroyed the viability of pollen without injury to other floral organs. Treatments at 0° to about 6° C gave similar but probably less effective results. Florets opened less promptly at low than high temperature. Between 9° and 39° C pollen was unaffected. All tissues were injured at temperatures above 44° C. Treatments at about 43° C had no effect after florets opened and pollen had settled on the stigma.

Pollinations following emasculation by the hot water method gave the highest percentage of seed set. Germination of crossed seed obtained by this method was better because well developed seed, fully protected by the glumes, were obtained. Possibly fewer non-crosses occurred following the use of the hot water method than by the clipping method.

Advantages from the use of the hot water method include: (a) Elimination of injury to the glumes because the florets open in a normal manner; (b) pollinations are limited to mature florets since those that are immature do not open; (c) the tedium of removing anthers is eliminated; (d) the florets open and close prior to normal blooming in surrounding plants, making bagging unnecessary as a protection against wind pollination; (e) varieties having small florets that might be seriously injured by clipping can be pollinated readily; (f) normal seed which germinate well are obtained; and (g) expensive equipment, shelters, and the handling of potted plants are not required.

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REGISTRATION OF IMPROVED SORGHUM VARIETIES. I[1]

JOHN H. PARKER[2]

IN 1936, 73 varieties of sorghum were registered as standard varieties. Three improved varieties of sorghum were approved for registration in 1937, as follows:

Variety	Reg. No.
Club	74
Finney milo	75
Early Kalo	76

CLUB, REG. NO. 74

Description.—Plants midseason, midtall; stems midstout, mid-juicy, not sweet; tillers abundantly; branches sparsely; midleafy (10 to 12); midribs cloudy; leaf sheaths overlapping moderately; panicles erect, compact, ovoid to ellipsoid; rachis nearly continuous; rachis branches short to mid-long, appressed; glumes pubescent but pubescence partly deciduous at maturity, black, indurate, elliptic, apices obtuse; lemmas appear awnless but have short tip awns which usually do not extend beyond the glumes; stigmas creamy white; kernels much exposed in angles and extending well beyond apices of glumes, large, white with reddish-brown spots, nearly globose, endosperm starchy, corneous layer thin, nucellar layer absent; pedicellate spikelets large, straw-colored, and partly deciduous at maturity; coleoptiles green.

Club is from a head selection made by A. F. Swanson in a head row of Dawn kafir grown at the Hays, Kansas, Branch Experiment Station in 1926. Valuable characteristics of Club are its ability to produce high yields in regions where the season is long enough to permit maturity and under favorable moisture conditions, its immunity to the Pythium disease of milo, its relatively high resistance to chinch bug injury, and relatively low infection by kernel smut.

Average yields of club and other varieties tested at Hays, Kansas, during the 8 year period 1929–1936 are as follows:

Variety	Yield, bu. per acre
Kalo	32.7
Club	**29.1**
Feterita	28.1
Modoc	26.5
Western Blackhull kafir	26.2
Dwarf Yellow milo	24.7
Pink kafir	22.4
Dawn kafir	21.4

[1]Registered under the cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 24, 1937.

[2]Agronomist, Kansas Agricultural Experiment Station, and Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1936 Committee on Varietal Standardization and Registration of the Society charged with the registration of sorghum varieties.

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FINNEY MILO, REG. NO. 75

Description.—Finney milo is very similar to Dwarf Yellow milo except in being resistant to Pythium root rot, about two days later in maturity and in having more erect upper leaves.

A selection from Dwarf Yellow milo made in 1930 by F. A. Wagner, Superintendent of the Garden City, Kansas, Branch Experiment Station. This selection, named in February, 1937, after Finney County, Kansas, has been grown in nursery rows, field plats, and seed fields at Garden City, Tucumcari, New Mexico, Dalhart, and Chillicothe, Texas, and at other stations, in direct comparison with the parent variety, Dwarf Yellow milo. In all these tests on diseased soil, Finney shows a striking contrast and marked advantage over its parent, often yielding 62 to 75 bushels per acre under irrigation compared to very low yields or failure of the susceptible parent. In 15 cooperative wheat variety tests on Kansas farms during the four years of 1934–1937, Finney milo produced an average yield of 20.0 bushels per acre as compared with 21.3 bushels for Dwarf Yellow milo.

Publication.—WAGNER, F. A. Reaction of sorghums to the root, crown, and shoot-rot of milo. Jour. Amer. Soc. Agron., 28:643–654. 1936.

EARLY KALO, REG. NO. 76

Description.—Plants very early; short (average about 40 inches); stems slender, mid-juicy to dry, not sweet; tillers mid-freely; branches sparsely; leaves few (7–9); midribs cloudy; leaf sheaths overlapping slightly; panicles erect, mid-compact to effuse, ellipsoid to cylindric; rachis about 80% of head length; rachis branches mid-long; glumes pubescent but pubescence partly deciduous at maturity, black to reddish-brown, slightly chartaceous, elliptic, apices obtuse; lemmas usually awned; stigmas yellow; kernels much exposed and extending beyond apices of glumes, mid-size, salmon-yellow with black or dark-red spots, obovoid, endosperm starchy, corneous layer mid-thick to thick, nucellar layer absent; pedicellate spikelets small, reddish-brown, and deciduous at maturity; coleoptiles red.

A selection from Kalo made by A. F. Swanson at the Hays, Kansas, Branch Experiment Station in 1931, from Kalo, which is a selection made at Hays in 1921 from a natural cross between Pink kafir and Dwarf Yellow milo. Early Kalo is about 10 days earlier in maturity than Kalo and the plants are shorter. Because of its earliness, Early Kalo is suited to regions of shorter growing season than Kalo, such as northwestern Kansas and the vicinity of North Platte, Nebr. Early Kalo has been increased for distribution to farmers by the North Platte Experimental Station and is being certified by the Nebraska Crop Growers Association.

Average yields of Early Kalo and other sorghum varieties at Hays for the four-year period, 1933–1936, are as follows:

Variety	Yield, bu. per acre
Feterita	12.8
Early Kalo	**11.2**
Kalo	10.3
Modoc	7.4
Weskan	6.9
Day milo	6.8
Club	5.5
Dwarf Yellow milo	5.2
Pink Kafir	5.1
Wheatland milo	4.6
Western Blackhull kafir	4.3
Dawn kafir	3.2

Publication.—ZOOK, L. L. Grain and forage sorghum varieties at the North Platte Experimental Substation. North Platte, Nebr., Exp. Substa. Bul. 38: 5. 1936.

A SIMPLIFIED METHOD FOR TESTING THE LODGING RESISTANCE OF VARIETIES AND STRAINS OF WHEAT[1]

I. M. ATKINS[2]

A NEW method for testing the strength of straw, or lodging resistance, of wheat varieties and strains has been used successfully at Texas Substation No. 6, Denton, Texas, in the past two seasons. A preliminary description of this method has been given in a previous paper.[3] Further simplification has been accomplished during the past season and a description of the method is herewith presented. Additional data relating to its accuracy and practicability are also given.

METHODS AND APPARATUS

The methods and apparatus herein described were developed after a detailed study by the author[4] of morphologic characters associated with lodging in 129 varieties of winter wheat in the 1933 and 1934 seasons. The morphologic character found to be most closely associated with strength of straw, as measured by the Salmon breaking strength machine,[5] was the weight of a section of the culm taken near the base of the plant. These sections are termed "weight per unit length" in this and the previous paper. In the earlier tests these samples were obtained by cutting, with ordinary scissors, sections 10 cm in length from the culm. They were cut about two or three inches above the crown of the plant or near the first straight internode and included one node and parts of two internodes. Strength of straw tests were made with the same sections. The weight of these sections was found to correlate almost perfectly ($r = 0.968$ for a 3-year average) with breaking strength.

During the past season an instrument for accurately and rapidly cutting these sections was made. This cutter, size and dimensions of which are shown in Fig. 1, was made by a local blacksmith from two sections of ¼-inch steel plate. The sections of steel are shaped to fit over one another and, after sharpening, operate much the same as a double paper cutter. The space between the jaws is such that 10 cm sections of the culm are cut.

Samples are obtained by cutting the culms at the surface of the ground with a hand sickle and usually are placed in a shed to dry

[1]The studies herein reported were conducted cooperatively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station. Received for publication January 22, 1938.

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[3]ATKINS, I. M. Relation of certain plant characters to strength of straw and lodging in winter wheat. Jour. Agr. Res., 55: 99–120. 1937.

[4]*Loc. cit.*

[5]SALMON, S. C. An instrument for determining the breaking strength of straw. Jour. Agr. Res., 43: 78–82. 1931.

FIG. 1.—Straw cutter used in securing samples for weight per unit length of culm.

before cutting the sections. The upper part of the plant and heads may be discarded or saved for seed as desired. Adjustment of the culms before cutting so that all sections will be comparable with respect to number of nodes has been found unnecessary. Usually each section will include one node only. The leaf sheath is not stripped from the culm although dead loose leaves are discarded. From 100 to 300 sections are cut from each plat. Weighings are made in groups of 100 sections. If large plats of grain are to be tested, additional samples should be taken or, if available, samples should be taken from several replications to give greater accuracy. Fig. 2 shows the cutter in operation. Bundles of 100 culm sections from strong, moderately strong, and weak-strawed varieties of wheat ready for weighing are shown in Fig. 3.

EXPERIMENTAL DATA

Data showing the interrelations between weight per unit length of culm, breaking strength of straw, and lodging for winter wheat grown at Denton, Texas, are presented in Table 1. Correlation coefficients between breaking strength of straw and weight per unit length were calculated for all 118 varieties grown for this study, but coefficients between lodging and weight per unit length and between lodging and breaking strength of straw were cal-

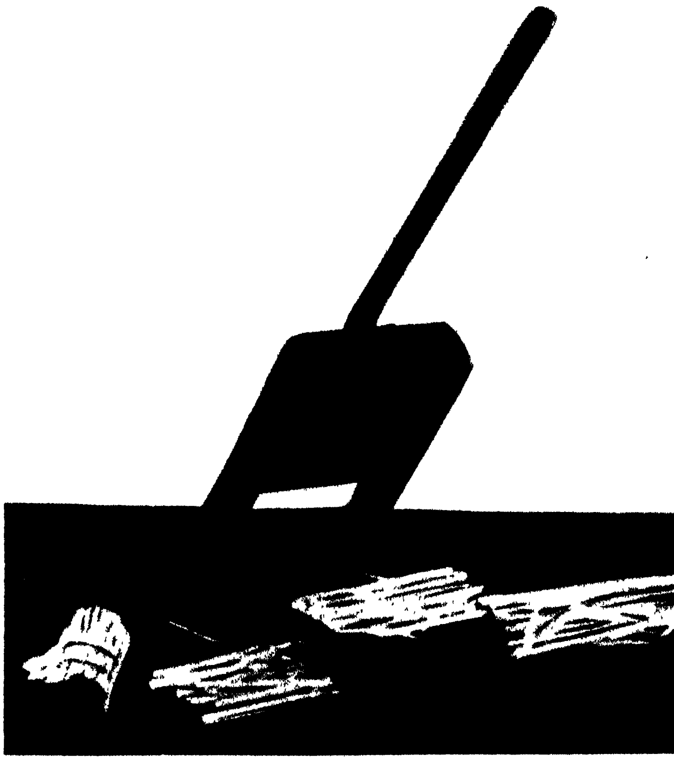

FIG. 2.—Straw cutter in operation with a sample of 100 culms at the left, ready for weighing.

FIG. 3.—Wide variation in size and weight of 100-culm sections cut from strong, moderately strong, and weak-strawed varieties of wheat. A, Sol, 15.7 grams; B, Nittany, 14.8 grams; C, Prosperity, 14.6 grams; D, Red Chief, 14.0 grams; E, Clarkan, 12.8 grams; F, Denton, 10.4 grams; G, Sherman, 7.9 grams; H, Turkey, 7.6 grams; I, Kanred, 7.4 grams.

culated for those varieties only which lodged, that is, for 68 varieties. Two samples of 100 culms each were weighed from each variety in 1936. The correlation coefficient between samples was 0.868.

TABLE 1.—*Interrelations between weight per unit length of culm, breaking strength of straw, and lodging, at Denton, Texas.*

Characters compared		Number of varieties	Correlation coefficient
Breaking Strength	Breaking Strength		
1933	1934	30	0.533
1933	1936	30	0.581
1934	1936	118	0.631
Weight per Unit Length	Breaking Strength		
1934	1934	118	0.918
1936	1936	118	0.948
Av. 1933–36	Av. 1933–36	30	0.968
Av. 1934–36	Av. 1934–36	118	0.945
Weight per Unit Length	Weight per Unit Length		
1933	1934	30	0.690
1933	1936	30	0.611
1934	1936	118	0.721
Lodging in the Field	Breaking Strength		
Av. 1932–36	Av. 1933–36	30	—0.586
Av. 1932–36	1933	30	—0.510
Av. 1932–36	1934	30	—0.443
Av. 1932–36	1936	30	—0.530
1936	Av. 1934–36	68	—0.418
1936	1934	68	—0.405
1936	1936	68	—0.356
Lodging in the Field	Weight per Unit Length		
Av. 1932–36	Av. 1933–36	30	—0.619
Av. 1932–36	1933	30	—0.520
Av. 1932–36	1934	30	—0.552
Av. 1932–36	1936	30	—0.570
1936	Av. 1934–36	68	—0.428
1936	1934	68	—0.380
1936	1936	68	—0.393

Least significant value of r for 30 varieties = 0.449; 68 varieties = 0.302; 118 varieties = 0.254.

It will be observed that the weight per unit length is closely correlated with strength of straw, and also that the interannual coefficients for weight per unit length are high. This determination also is significantly correlated with lodging. With one exception, these later coefficients are higher than are similar coefficients for breaking strength of straw and lodging. Usually, more than a single year's data on lodging and breaking strength of straw or weight per unit length are necessary to demonstrate significant relations. It is of interest to note, therefore, that in 1936 the coefficients for lodging and breaking strength and for weight per unit length and lodging are both significant. This appears to have been due to the fact that the lodging which occurred in 1936 was not influenced by strong winds or other disturbing factors and more nearly reflected the true strength of straw than can usually be expected.

In 1937, samples were secured from all plats of the replicated breeding nursery at Denton. A total of 94 varieties were grown in this nursery, which was arranged in a modified Latin square with four replications of each variety. Varieties were randomized within each replication with the usual restrictions for modified Latin squares. The correlation coefficients between series in this nursery were all between 0.7 and 0.8. No lodging occurred in 1937 and hence no coefficients for lodging and weight per unit length were calculated.

In addition to being accurate and simple, the determination of weight per unit length of culm requires much less time than determining the breaking strength of straw. In 1936, samples were cut and weighed from 70 varieties in one 8-hour day. It would have taken two men at least two weeks to have made determinations of strength of straw for the same material.

AGRICULTURAL METEOROLOGY AND CROP FORECASTING IN WESTERN CANADA[1]

J. W. Hopkins[2]

INVESTIGATIONS in agricultural meteorology may be conveniently classified under three broad headings, depending upon whether their objective is (a) descriptive or comparative meteorology, (b) correlation of meteorological factors with crop growth and development, or (c) crop forecasting with respect to both quantity and quality.

In studies of type (a), detailed information is sought respecting not only the average values over a period of years of the weather elements characteristic of given districts, but also the manner in which these may be expected to vary from season to season. In addition to its purely descriptive value, such information may suggest sources of crop variation previously overlooked.

Categories (b) and (c) have been separated because in (c) one is free to aim at the formulation of a regression equation which will reliably predict the final outturn of crop from antecedent observations, regardless of whether the terms included in the equation have any explicit biological significance or not. In b, on the other hand, one is interested not only in the end result, but also in tracing through the influence of successive causal factors on the actual developmental sequence; information which may be important in the appraisal of cultural methods or in the formulatoin of plant breeding programs.

Actually, of course, these three aspects of the subject are mutually inter-connected, and, under Canadian conditions at least, it would seem to be impossible to prosecute (c) successfully if (a) and (b) are neglected. The reasons for adopting this view are illustrated by the following comments respecting the problem of forecasting the western Canadian wheat crop.

This crop, as is well known, is subject to great annual vicissitudes. Since weather conditions are generally agreed to be a major factor in the fluctuation of acre yields from year to year, and since these operate on the crop from the beginning of its growth, it has naturally been suggested that if the relation between weather conditions during successive periods of the growing season and the subsequent crop yields could be determined, justifiable approximate estimates of the probable forthcoming production might be made at an earlier date than is now feasible, and could be periodically improved upon as the season advanced and further weather data became available.

This, of course, presupposes that adequate series of reliable yield data are available for correlation with the meteorological observations. In Canada, at any rate, this is far from being the case, and an important advance might be made if a set of permanent agrometeorological

[1]Contribution from Division of Biology and Agriculture, National Research Laboratories, Ottawa, Canada. Also presented at the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication December 27, 1937.

[2]Statistician.

plots were established and maintained at each of the Dominion Experimental Farms and Stations within the wheat zone, in order to accumulate over a period of years comparable data with respect to the standard varieties.

Moisture supply is probably the most important single factor influencing yield. The moisture available to the western Canadian spring wheat crop consists of the amount present in the soil at the time of sowing, supplemented by the quantities accruing from rainfall during the growing season. Under prairie conditions both combined are seldom equal to the absorptive capacity of the crop. This is illustrated by the results of soil moisture experiments made at Swift Current, Saskatchewan, by Barnes and Hopkins (2).[3] Crops were grown in tanks, 15 inches in diameter and 5 feet deep, filled with soil and placed in pits in the centre of field plots growing the same crops as those in the tanks. Periodic weighing of the tanks by means of a travelling gantry permitted changes in soil moisture to be followed. By this procedure, it was found that in 1928, for example, only during a period of about two weeks out of the whole growing season was moisture received from rainfall in amounts sufficient to offset the quantities used up in transpiration and evaporation.

Of course, the initial soil moisture, and the subsequent balance of loss and gain, vary from year to year owing to differences in the precipitation prior to and during the growing season. Since the results of these tank experiments over a period of years (1) indicate a rather close relation between available soil moisture and yield, it might be thought that there would consequently be a close correlation between yield and precipitation. Statistical studies by the author (6, 7), however, yielded multiple correlation coefficients of only 0.7–0.8 between yield per acre in various crop districts of Alberta and Saskatchewan and precipitation during the growing season and the preceding autumn. While these are quite significant statistically, unfortunately the degree of association indicated is not high enough to be of practical utility in crop forecasting. The annual acreage sown to wheat in Canada is of the order of 25,000,000, and the average production for the 11-year period 1926–36 approximately 367,000,000 bushels. Hence, in order to reduce the standard error of estimate to 20,000,000 bushels, which is roughly 5½% of the mean, the residual standard deviation from the regression equation must be less than 1 bushel per acre.

The fact that a higher correlation of yield with precipitation was not obtained may be due, of course, to the effect of other factors on the crop, and also, as was pointed out in the original paper, to imperfections in the data themselves. However, a study of the incidence of precipitation in the area concerned (10), suggests that part of the discrepancy may be due to the fact that not all of the rainfall recorded by rain gauges contributes in an equal manner to the supply of soil moisture.

The heights of the columns in Fig. 1 show graphically the frequency of occurrence of different daily totals of precipitation (exclusive of

[3]Figures in parenthesis refer to "Literature Cited," p. 321.

zero) over a 17-year period at four representative points in the wheat area during each of the five months of the growing season. The daily totals are grouped in ascending classes of 1/10 inch, and in all cases the smaller daily amounts are seen to be much the more numerous.

Fig. 2 shows the actual quantities of rain accruing from the different classes of daily amounts. As before, the grouping is by ascending intervals of 1/10 inch, but in this case the total height of the columns

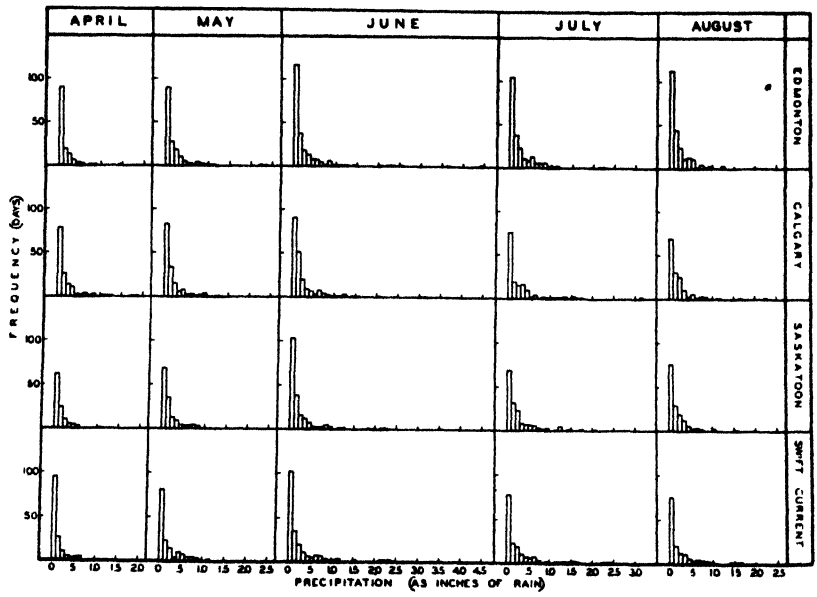

FIG. 1.—Frequency distribution of daily totals of precipitation (excluding zero) at meteorological stations in central and southern Alberta and Saskatchewan during five spring and summer months, 1916–1932.

is proportional not to the frequency of occurrence, but to the total inches of rain contributed over the 17-year period. The larger daily amounts, whose infrequency caused them to figure so inconspicuously in the preceding diagram, are now seen to provide an appreciable proportion of the total, particularly in June and July.

The solid black columns in Fig. 2 represent the total rain received in the various categories of daily amounts during the eight-driest Aprils, Mays, etc., of the 17-year period (1916–1932). The concentration of these in the left-hand portion of each cell of the diagram indicates that, during the drier months, a major part of such precipitation as did occur consisted of relatively light showers. There is thus a qualitative as well as a quantitative difference between the months of above and below average precipitation.

This is a factor which must be taken into account in attempts to correlate crop yields with precipitation, for under prairie conditions not all of the moisture received at any time as rain penetrates into

the soil and becomes available to plants. A certain amount is retained by the surface layer and subsequently evaporated directly into the atmosphere. The amounts thus lost, which will depend on soil type, vegetational cover, and the meteorological conditions subsequent to precipitation will determine a lower limit of effective rainfall. In consequence, the efficiency of conservation by the soil of different amounts of rain will not be the same, and three separate falls of 0.25

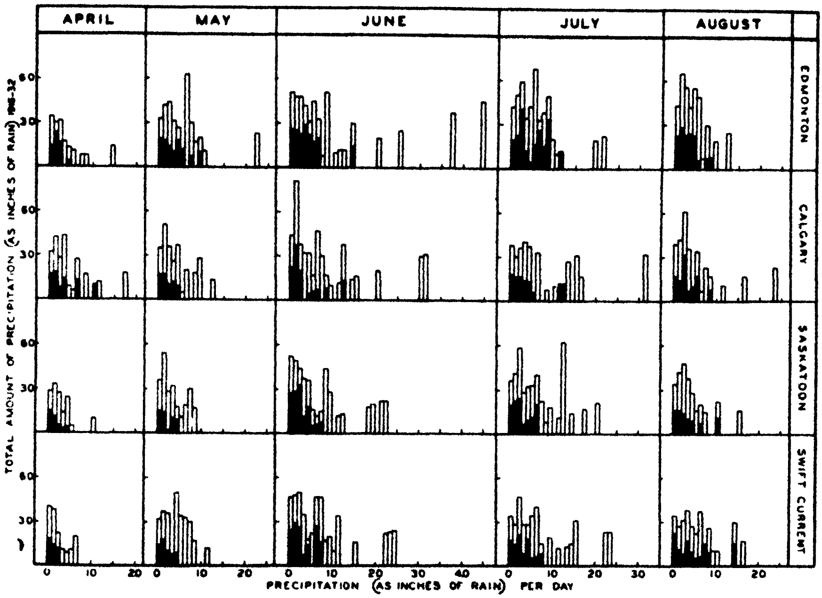

FIG. 2—Proportion of total precipitation at meteorological stations in central and southern Alberta and Saskatchewan during five spring and summer months, 1916–1932, received in daily amounts of specified sizes. A, during entire period (total height of column); B, during the eight driest Aprils, Mays, etc., at each station (lower blackened portion).

inch, for example, cannot be assumed to be equivalent in effect to one fall of 0.75 inch.

The actual penetration into the soil of individual rainfalls has not, as far as the writer knows, been studied in any great detail in Canada. A study of this sort would certainly seem to be desirable in view of the fact that the data shown in Fig. 2 indicate that in the 8 driest Aprils out of the 17 considered, from 54% to 100% of the total rain at the four stations was in daily amounts of 3/10 inch or less, and that even in June small falls of this nature constituted on the 8-year average from 45% to 68% of the total.

When the records for individual years are examined, even more striking contrasts are revealed. Thus, a study of the June rainfall at Calgary and Saskatoon in each of the 17 years 1916–1932 (10) shows that in the moister months, the proportion of the total occurring in daily amounts of 3/10 inch or less was in the neighborhood of 20%.

In months of smaller total precipitation it was on the average higher, but fluctuated considerably, in some instances attaining 100%, in others being only of the order of 40%, and in one year at Saskatoon only 10% of a June rainfall totalling but 2.04 inches occurred in amounts of 3/10 inch per day or less. Even in periods of below-average moisture, therefore, similar amounts of total precipitation may be of quite different effectiveness in different seasons.

As is well known, the amount of precipitation during an individual rainstorm sometimes shows considerable local variation. This is a subject which has recently been investigated on a comprehensive scale in Oklahoma by the Division of Climatic and Physiographic Research of the Soil Conservation Service (17), with very illuminating results. Comparable detailed observations are not available in Canada, but some information has been obtained from the 10-year records of daily precipitation during the spring and summer months at a series of meteorological stations in each of four districts representative of central and southern Alberta and Saskatchewan. Over the 10-year period 1923–1932, local variation in the total rainfall received at different stations in the same district during the same month was found to result in a standard deviation of no less than 40% to 50% of the mean; while if, instead of the total of all rain received during the month, attention is confined to the quantity received in amounts exceeding 3/10 inch per day, the local variations in this give rise to a standard deviation of from 50% to 70% of the mean, indicative, of course, of an asymmetrical frequency distribution. Thus, the same total amount of rainfall may be the outcome of appreciably different intensities of precipitation, not only from year to year at the same point, but from point to point during the same year. This increases the desirability of rainfall penetration studies, for not much success is likely to be attained in attempting to correlate crop yields with soil moisture which is nonexistent.

Temperature conditions in western Canada are more stable from year to year than are the amounts of precipitation (6). Annual variations are most pronounced in the spring, and indications have been obtained from statistical studies (6) that above-average temperatures at this time have a favorable effect upon wheat yield, whereas in midsummer their effect appears to be depressive. On the whole, though, it would seem that the effect of temperature on yield is secondary to that of rainfall. Furthermore, during the summer months at least, annual variations in temperature are to some extent correlated with those of precipitation (11), above-average rains being associated with below-average temperatures.

It has been shown (8, 9), however, that temperature conditions during the period of formation and ripening of the wheat grain may affect an important quality factor, namely, protein content. Above-average temperature during this period of crop development has been found to be associated with an increased percentage of nitrogen in the mature grain. This is presumably the result of an actual reduction in carbohydrates due to accelerated respiration, the few quantitative studies that have been made with wheat indicating that the rate of

respiration is in fact approximately doubled by each 10° C rise in temperature.

When one seeks to correlate crop growth or yield with temperature observations, two questions respecting such observations arise.

The first of these is whether the so-called "mean daily temperature" calculated by averaging the daily maximum and minimum is in fact a reliable estimate of the true daily mean. Average diurnal temperature curves (11) for the spring and summer months obtained from hourly observations at Swift Current, Saskatchewan, are all to some extent asymmetrical, the number of hours from minimum to maximum being less than that from maximum to minimum, particularly, of course, in spring when the days are shorter. One might expect, therefore, that the mean of maximum and minimum would tend to over-

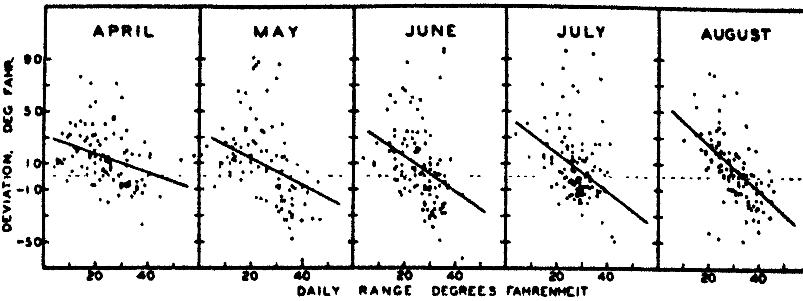

FIG. 3.—Relation between deviation of two-point from 24-point daily mean, and daily range in temperature at Swift Currents, Saskatchewan. Computed from four years' data (1922, 1923, 1925, and 1927).

estimate the true daily mean, and this does in fact seem to be the case, as for all five months studied it gives values which are on the average higher than those obtained from the 24 hourly observations. The average discrepancy, which seems to be a function of the season, ranges from +1.74° F in April to +0.74° in July. It is thus of moderate dimensions. However, the discrepancies actually occurring on individual days at this station vary considerably, as is shown by the vertical scatter of points in Fig. 3. The maximum difference in the 4-year period to which these data refer is +9.7° F, which occurred during the month of June.

The source of such deviations, of course, is to be found in the various departures of the actual daily temperature sequences from the average diurnal trend, and it may be noted that there is some correlation between the daily range in temperature and the difference in the two averages. Such discrepancies will, of course, be of most importance in connection with processes such as respiration, which vary in a non-linear fashion with temperature.

The second question is whether the readings of thermometers placed in the usual standard screens provide an adequate indication of the temperature conditions actually experienced by the crop. Micrometeorological studies in both Europe and India (4, 15, 16) indicate that this may not always be so. However, a suitable series of observations

under the environmental conditions actually prevailing in western Canada would seem to be required in order to settle this point.

The effect of wind upon crops is a subject about which little is known. Reference is intended, of course, not to mechanical damage, but to effects arising from alterations in the transpiration rate. Martin and Clements (13) exposed sunflower plants in the greenhouse to artificial winds of different velocities and obtained striking results, not only upon transpiration, but also upon growth in general as measured by the production of dry matter. In so far as crop growth is concerned, the importance of wind as a factor will depend first of all upon the extent to which it varies from year to year, and secondly, upon whether the effects of such variations on plants growing in the mass in the field are as pronounced as those observed in plants growing individually in the greenhouse.

So far attention has been confined to meteorological elements which, although they may vary in amount or intensity, are present in all seasons. There are also, of course, factors of the catastrophic class, such as frost and hail, which, although of relatively infrequent occurrence, may nevertheless on occasion produce appreciable effects. It is therefore necessary to have some quantitative method of estimating the reduction in yield resulting from such events. In this connection a promising line of approach has been developed by American workers in investigating the effects of mechanical injury in simulation of hail damage, and determining the effect on yield of corn (3) and flax (12) of differences in the degree of injury and time of infliction.

Plant diseases may also be considered to fall in this category. The degree to which these establish themselves and develop is generally believed to be dependent on environmental factors. From the work already done by several investigators, however, it is apparent that the relation between weather conditions and pathogen development is by no means simple, and it will probably be found most practical to compute the effect on yield from visual or other estimates of the actual degree of infestation at specified stages of crop development.

Thus, Greaney (5) has found from field experiments extending over 8 years a linear relation between the extent of infection by black stem rust and the reduction in yield of Marquis wheat, each additional 10% infection resulting on the average in a loss of 5.4% of the possible crop. By appropriate methods, similar relations could no doubt be worked out for other plant diseases. It may be necessary to do this for individual varieties. Rust-resistant hybrids, for example, have now been produced and in the course of a few years will be extensively grown in sections of Manitoba and Saskatchewan. The introduction of notably drouth-resistant varieties would, of course, require meteorological correlations in general to be worked out on a varietal basis.

Some mention should also be made of the factor of weed competition. As a result of the extensive type of farming practiced, weed infestation has attained serious proportions in many areas of western Canada. Barnes (1) is of the opinion that under conditions of limited rainfall, competition for the available soil moisture by weeds consti-

tutes a greater hazard to crop growth than either plant diseases or insect pests, and presents experimental data showing striking reductions in wheat yield at Swift Current, amounting in one year to over 75%, as a result of competition from Russian thistle.

Pavlychenko and Harrington (14) have pointed out that normally the development of cereal plants with respect to both tops and roots is at the outset much more rapid than that of any of the dicotyledonous weeds they studied, except wild mustard. Under favorable conditions, therefore, this capacity for rapid initial development should enable cereals to take more or less complete possession of the available soil area before the weeds attain sufficient growth to compete seriously with them. By 21 days after emergence, however, it was found that most noxious weeds had both greater root systems and larger assimilation surfaces than had any of the cereals studied, with the result that no cereal crop can compete successfully with them after this stage of development. Consequently, any circumstance which retards the early development of the cereals also reduces their subsequent competitive efficiency.

There is thus the possibility of an important indirect influence of early weather conditions on yield, due to a shift in the competitive balance. Here again, however, it will probably be found most practical to devise some simple means of specifying the intensity of weed infestation from observations on the growing crop, and to determine the effect of variations in infestation from year to year on the yield of infested in comparison with weed-free stands. Data bearing on this latter question are gradually being accumulated by the Associate Committee on Weed Control of the National Research Council of Canada.

It may be judged from the foregoing remarks that, in the view of the writer at least, the determination of the regression equations necessary to predict Canadian wheat production from meteorological observations with the degree of accuracy required in practice will be a lengthy and tedious process, requiring the accumulation and analysis of large numbers of appropriate observations. It may well be that as far as the routine procedure of crop forecasting is concerned, the most effective method is that of observations on the growing crop along the lines of the English scheme (18), supplemented perhaps by later meteorological and ancillary data. The elucidation of the actual mode of action and interaction of the various weather elements on growth and yield remains, however, a subject of sufficient interest and importance in itself to justify continued attention.

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GERMINATION TESTS WITH SUGAR BEET SEED[1]

A. W. Skuderna and C. W. Doxtator[2]

CONSIDERABLE difference in methods used for conduct of germination tests with sugar beet seed exists among laboratories interested in this work. It has been the custom of the German seed trade[3] to prescribe the use of fine-grained quartz sand, moistened to 60% of its moisture-holding capacity, as a "germination bed" for sugar beet seed. The containers used are of porcelain ware such as soup plates or bread tins. A representative sugar beet seed sample is weighed to ascertain number of seed balls per gram and kilogram. The sample is then reduced to 100 seed balls. These are lightly pressed into the sand, a piece of window glass is placed over the container, and left in place during the 14-day period of test. An alternating temperature of 30° C for 6 hours and 20° C for 18 hours is maintained during the period of the test. The reading of germinating seed balls and sprouts therefrom is made at the end of 7 days and 14 days, respectively. Results are reported in percentage germination per 100 seed balls, number of sprouts per 100 seed balls, and number of sprouts per kilogram of seed. This method is being used by many of the U. S. Beet Sugar Company laboratories in determining whether the seed purchased comes up to the prescribed Magdeburg standard on which European and domestic beet seed is purchased.

The Association of Official Seed Analysts of North America[4] recommend the soaking of beet seed for 2 hours at a temperature of 20° C before germination; the use of folded blotting paper instead of sand; and the making of a preliminary count of germinating seed balls in 4 days and the final count in 10 days. There is a further recommendation that the germination of beet seed be confined to the determination of the percentage of balls that sprout.

Still another modification of these methods is used by one commercial seed testing laboratory[5] in which the soaked seed is placed for one day into a warm germinating oven maintained at 30° C and then alternated between the warm and cold germinating ovens for the balance of the germination period. Counts are made on the 4th, 7th, 11th, and 14th day of the test. Only sprouts showing normal root and root hair development are considered normal and are counted.

The purpose of this paper is to present results from a series of tests in which the various methods mentioned and others are compared, and to propose a uniform method of procedure in the conduct of sugar beet seed germination tests.

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[1]Contribution from the American Beet Seed Company, Rocky Ford, Colorado. Received for publication January 11, 1938.

[2]General Manager and Plant Breeder, respectively. Acknowledgment is due to Miss Elizabeth Seamans, station clerk, for capable assistance in obtaining data used in this paper.

[3]German regulations (norms) governing the trade in sugar beet seed. Madgeburg, Germany. 1914.

[4]Rules for seed testing. U. S. D. A. Cir. 406. 1928.

[5]Correspondence received by senior author.

MATERIALS AND METHODS

THE SEED SAMPLE

A representative lot of home-grown seed, 1936 crop, was used throughout the study to insure uniformity of seed for the comparative tests discussed in this paper. The seed lot was thoroughly composited by splitting the sample with a Boerner grain sampler, first to a 20-gram sample and subsequently further reducing it to approximately 100 seed balls. This random selected 100 seed ball sample was compared as to germination with a seed sample specially prepared so as to conform in percentage amounts to the various sizes of seed balls present in the seed lot. The seed ball size and percentage amount was determined by placing the seed for 5 minutes in a mechanical shaker having screens of 4.00-mm; 3.5-mm; 3.0-mm; and 2.5-mm size, weighing the amount of seed remaining on each screen, and using the proportions found in preparation of the 100 seed ball selected sample. For each comparison, four tests of 100 seed balls each were made.

THE SUBSTRATUM

A paper toweling of an absorbent weight, 11 by 15 inches in size, folded double, was used as a substratum, making a 5½ inch by 7½ inch seedbed. In these tests it was found that this grade toweling supplied the needed moisture and allowed sufficient aeration, provided due care was used to prevent excess wetting of the toweling.

Standard germination blotting paper (granite) of 250-m weight was used as a substratum. The sheets were cut 8 by 9½ inches and folded in half, making a 4¾ by 8 inch seedbed.

Fine-grained river sand screened through a 35-mesh screen was used for the sand substratum. This sand was washed free from alkali salts, sterilized with live steam and placed in porcelain containers 7½ by 11½ inch in size, filled about ¾ inch deep. The sand was moistened to 60% of its calculated moisture-holding capacity.

THE WATER

Tap water and distilled water were compared in these tests. The tap water was derived from artesian sources, having a mixed salt content of approximately 800 p. p. m., the salts being mostly sodium.

For comparison tests the tap water was distilled and both sources of water used separately to soak seed and to moisten paper toweling, blotting paper, or sand as required by the test in question.

THE GERMINATORS

Two Minnesota seed germinators, thermostatically controlled, were used in the tests. One of the germinators was kept at a temperature of 20° C and the other at 30° C. The seed trays from one germinator were transferred as required from one germinator to the other, assuring thereby a sharp fluctuation in temperature.

THE GERMINATION TEST

Particular attention was given to the fulfillment of requirements of each test. For those tests indicating soaking of seed, this was done for 2 hours in water at 20° C. In all tests requiring an alternation of temperatures, this was accomplished by germinating the seed for 16 hours at 20° C and 8 hours at 30° C. Germination counts were made at 4, 7, and 14 days. Results of only 7- and 14-day germinations are given for the "A" series of tests. In making germination counts, only sprouts

showing normal root and root hair development were counted, and a record kept of vigor and condition of seedling. The sprouted seed balls were removed to an empty blotter at the time germination counts were made. The sprouts were counted and removed from the seed balls and final count made on the 14th day.

DESCRIPTION OF TESTS

A total of 84 individual tests, each repeated in quadruplicate was made in the "A" series. The detail is as follows:

Series A.—1. Comparison of 30° C temperature for first 24 hours and then alternating at 20° C for 16 hours and at 30° C for 8 hours for duration of test (method designated as R) versus standard procedure (S) wherein the temperature was alternated at 20° C for 16 hours and 30° C for 8 hours from beginning of test. Test 1–24, inclusive.

2. Comparison of continuous 20° C versus continuous 30° C temperature for entire period of test. Tests 25–48, inclusive.

3. Seed ball size (4.0 mm; 3.5 mm; and 2.5 mm) versus random size in relation to germination of sugar beet seed. Tests 49–84, 4–6, 10–12, 16–18, and 22–24, inclusive.

4. Comparison of type of substratum, paper toweling, blotter, and sand. Paper toweling, tests 1–4–7, and every third test to 82, inclusive. Blotter, tests 2–5–8, and every third test to 83, inclusive. Sand, tests 3–6–9, and every third test to 84, inclusive.

5. Comparison of presoaking beet seed for 2 hours prior to germination versus dry seed. Tests involving presoaked seed 13–24; 31–36; 43–48; 55–60; 67–72; and 79–84, inclusive. Tests involving dry seed 1–12; 25–30; 37–42; 49–54; 61–66; 73–78, inclusive.

6. Effect of tap water versus distilled water in presoaking seed. Tap water, tests 13–18; 31–33; 43–45; 55–57; 67–69; and 79–81, inclusive. Distilled water, tests 19–24; 34–36; 46–48; 58–60; 70–72; and 82–84, inclusive.

7. Effect of tap water versus distilled water in moistening the substratum. Tap water used in tests 1–6; 13–18; 25–27; 31–33; 37–39; 43–45; 49–51; 55–57; 61–63; 67–69; 73–75; and 79–81, inclusive. Distilled water used in tests 7–12; 19–24; 28–30; 34–36; 40–42; 46–48; 52–54; 58–60; 64–66; 70–72; 76–78; and 82–84, inclusive.

Series B.—1. Comparison of 4-, 7-, 10-, and 14-day period of germination to determine minimum period required. Forty sets of samples of sugar beet seed used other than those included in the A series.

2. Comparison of sand, soil, and blotting paper substratum (1935 tests) and 4-, 7-, 10-, and 14-day periods of germination.

3. The effect of presoaking sugar beet seed for 2 hours prior to germination test on germinability of seed of different ages. Seed of 6, 18, and 30 months of age used with sand as substratum.

EXPERIMENTAL DATA

Comparison of 30° C temperature for first 24 hours and alternating for balance of the germination test at a temperature of 20° C for 16 hours and 30° C for 8 hours daily (R method), with an alternating temperature of 20° C for 16 hours and 30° C for 8 hours for the entire period of test (S method) gave results shown in Table 1.[6]

[6]The analysis of variance method was used in the reduction of all data in this paper. Fisher, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 4. 1934.

TABLE 1.—*Comparing the "R" and "S" methods of germinating sugar beet seed (12 tests each), Rocky Ford, Colo., 1937.*

Days	"R" method		"S" method	
	A*	B*	A*	B*
7	82.10	176.27	81.85	168.02
14	86.50	184.75	85.50	177.54

Required for significance:
7 days, 6.38% germination and 19.90 number of sprouts.
14 days, 3.25% germination and 18.93 number of sprouts.

*A refers to germination and B to number of sprouts per 100 seed balls.

Comparing the results obtained from maintaining continuous temperature of 20° C versus 30° C for the entire period of the test, the figures given in Table 2 were obtained.

TABLE 2.—*Effect of continuous temperatures of 20° C and 30° C during period of test on germination of sugar beet seed (12 tests each), Rocky Ford, Colo., 1937.*

Days	20° C		30° C	
	A*	B*	A*	B*
7	80.58	172.42	80.15	162.88
14	87.50	185.08	85.15	172.50

Required for significance:
7 days, 7.09% germination and 25.07 number of sprouts.
14 days, 4.75% germination and 23.52 number of sprouts.

*See footnote to Table 1.

A combined analysis of the 48 tests involving the four temperature methods, "R" and "S" method, 20° C and 30° C for the 14-day germination percentage and the 14-day sprout counts was made. The analysis of variance is given in Table 3.

The 12 substrata moisture treatments which were used with the temperature methods were presoaking of seed in tap versus distilled water, versus dry seed. Each of the moisture treatments were used with the three substrata *viz.*, toweling, blotter, and sand.

To determine the effect of a selected sample compared to a random sample of beet seed, 12 comparison tests were made on each of the following seed ball sizes: 4.0 mm; 3.5 mm; 2.5 mm; and seed of random size obtained from the mechanically reduced sample of seed by use of a Boerner grain sampler. The results are shown in Table 4.

As indicated in the discussion of the seed sample, a seed sample was specially prepared so as to conform in percentage amounts to the various sizes of seed balls present in the lot of seed tested. The percentage amounts of each seed size in a 25-gram sample, together with the weighted germination of such a sample compared to the

TABLE 3.—*Analysis of variance of four temperature methods tested with 12 substrata and moisture treatments.*

Variation due to	Degrees of freedom	Sum of squares	Mean square	F*	Standard error
	14-day Germination, %				
Replication	3	14.277	4.7590	—	
Temperature methods	3	162.707	54.2356	6.47†	
Substrata and moisture treatments	11	581.537	52.8670	6.30†	
Temperature methods × substrata and moisture treatments	33	761.423	23.0734	2.75†	
Error	141	1182.722	8.3881	—	1.45
Total	191	2702.666			
	14-day Sprout Counts				
Replication	3	2031.938	677.3127	3.01†	
Temperature methods	3	5313.230	1771.0767	7.87‡	
Substrata and moisture treatments	11	6248.000	568.0000	2.53†	
Temperature methods × substrata and moisture treatments	33	13331.083	403.9722	1.80†	
Error	141	31713.562	224.9189	—	7.50
Total	191	58637.813			

*Obtained from Snedecor, G. W. Calculation and Interpretation of Analysis of Variance and Covariance Ames, Iowa: Collegiate Press, Inc. 1934.
†Exceeds the 5% point of significance.
‡Exceeds the 1% point of significance.

TABLE 4.—*Seed ball size in relation to germination of sugar beet seed, Rocky Ford, Colo., 1937.*

Days	4.0 mm.		3.5 mm.		2.5 mm.		Random size	
	A*	B*	A*	B*	A*	B*	A*	B*
7	89.81	217.02	84.98	163.27	69.52	109.54	81.85	168.02
14	92.79	224.56	87.79	168.90	74.00	118.86	84.88	177.54

Required for significance:
7 days, 2.58% germination and 7.41 number of sprouts.
14 days, 1.64% germination and 5.25 number of sprouts.

*See footnote to Table 1.

actual germination of the random selected sample, is as follows:

$$\frac{36.28\%\ (92.79) + 34.44\%\ (87.79) + 29.78\%\ (74.00)}{100} = \text{85.56\% weighted germination.}$$

The actual germination of the random sample was 84.88%. The required significance on the basis of 12 tests each is 1.15% germination and 3.68 number of sprouts per 100 seed balls.

To evaluate the influence of various substrata on the percentage germination and number of sprouts per 100 seed balls, 28 tests each

with paper toweling, blotting paper, and sand were made. The results are shown in Table 5.

TABLE 5.—*A comparison of paper toweling, blotting paper, and sand as a substratum for sugar beet seed, Rocky Ford, Colo., 1937*

Days	Paper toweling		Blotting paper		Sand	
	A*	B*	A*	B*	A*	B*
7	82.59	168.14	83.05	173.23	78.21	159.80
14	87.15	179.29	86.63	179.38	83.05	168.99

Required for significance between averages of 28 tests:
7 days, 3.83% germination and 6.78 number of sprouts per 100 seed balls.
14 days, 2.31% germination and 6.33 number of sprouts per 100 seed balls.

*See footnote to Table 1

Presoaking of seed for 2 hours prior to commencement of the germination test for the purpose of loosening the seedcap and causing the seed to absorb moisture more rapidly, has been widely practiced. To test the efficiency of this pretreatment, 42 comparison tests were made between presoaked and dry seed on a fresh crop of 1936 seed. The results are shown in Table 6.

TABLE 6.—*The effect of presoaking sugar beet seed for 2 hours prior to germination as compared to dry seed, Rocky Ford, Colo. 1937.*

Days	Presoaked seed		Dry seed	
	A*	B*	A*	B*
7	82.21	167.37	80.36	166.75
14	85.51	174.73	85.41	177.03

Required for significance between average of 42 tests:
7 days, 3.51% germination and 5.54 number of srpouts per 100 seed balls.
14 days, 1.13% germination and 4.79 number of sprouts per 100 seed balls.

*See footnote to Table 1.

In presoaking of seed, two different sources of water were used, tap and distilled. The tap water had an alkali salt content of approximately 800 p.p.m. The results from using this quality water compared to distilled water in presoaking seed are shown in Table 7.

TABLE 7.—*Effect of tap water compared with distilled water in presoaking beet seed with relation to germination results, Rocky Ford, Colo. 1937.*

Days	Tap water		Distilled water	
	A*	B*	A*	B*
7	81.25	167.29	81.32	166.83
14	85.57	176.24	86.65	175.52

Required for significance between average of 42 tests:
7 days, 3.51% germination and 5.54 number of sprouts per 100 seed balls.
14 days, 1.13% germination and 4.79 number of sprouts per 100 seed balls.

*See footnote to Table 1.

Tap and distilled water comparisons were also made with respect to effect on moistening the substratum, involving 14 tests for each comparison, the results of which are shown in Table 8.

TABLE 8.—*Effect of tap water compared with distilled water in moistening the substratum, Rocky Ford, Colo., 1937.*

Days	Test	Tap water			Distilled water		
		Paper toweling	Blotting paper	Sand	Paper toweling	Blotting paper	Sand
7.....	A*	82.14	83.75	77.86	82.98	82.36	78.57
14.....	A*	87.06	86.68	83.91	88.50	85.38	85.47
7.....	B*	166.57	176.20	159.10	169.71	170.27	160.50
14.....	B*	184.00	182.38	174.15	185.44	175.65	178.19

Required for significance between averages of 14 tests:
7 days, 5.42% germination and 9.52 number of sprouts per 100 seed balls.
14 days, 3.27% germination and 8.95 number of sprouts per 100 seed balls.

*See footnote to Table 1.

In 1936, a test was conducted with 40 sets of germination samples in quadruplicate in the comparison of 4-, 7-, 10-, and 14-day periods of germinating sugar beet seed. In this test, paper toweling was the substratum and the standard method of alternating temperatures was used throughout the test. The results are shown in Table 9.

TABLE 9.—*Comparison of 4-, 7-, 10-, and 14-day germinating periods on the germination percentage and sprout counts per 100 seed balls, Rocky Ford, Colo., 1936.*

4 Days		7 Days		10 Days		14 Days	
A*	B*	A*	B*	A*	B*	A*	B*
69.37	141.22	83.34	170.44	85.98	180.25	86.44	182.49

*See footnote to Table 1.

In a comparison test conducted in 1935, 35 germination test plantings each were made in sand, greenhouse soil, and in blotting paper to determine the merits of each. A temperature of 30° C was maintained throughout the test. The seed used was from the 1935 crop. The results are shown in Table 10.

TABLE 10.—*Comparison of sand, soil, and blotting paper as substrata for germinating sugar beet seed for 4-, 7-, 10-, and 14-day periods at 30° C, Rocky Ford, Colo., 1935.*

Substratum	4 days		7 days		10 days		14 days	
	A*	B*	A*	B*	A*	B*	A*	B*
Sand..........	70.5	141.5	76.0	175.0	81.5	181.0	82.5	183.0
Soil............	67.5	152.0	84.0	180.0	85.0	186.0	85.0	186.0
Blotting paper..	73.0	138.0	81.0	167.0	83.0	170.0	84.0	172.0

*See footnote to Table 1.

A number of tests were conducted in 1935 on presoaking of seed of different ages, using sand as the substratum and a 30° C temperature throughout the germinating period. Seed was presoaked in tap water for a period of 2 hours prior to germination. The results are shown in Table 11.

TABLE 11.—*The effect of presoaking sugar beet seed for 2 hours prior to germination on percentage germination and number of sprouts per 100 seed balls (sand substratum), Rocky Ford, Colo., 1935.*

Age of seed, months	Treatment	Percentage germination				
		4 days	7 days	10 days	14 days	Total, %
6	Presoaked	73.0	5.0	—	—	78.0
	Drv	67.5	4.5	3.0	—	75.0
Increase for presoaking						3.0
18	Presoaked	81.0	7.0	3.0	—	91.0
	Dry	72.0	9.0	4.0	2.0	87.0
Increase for presoaking						4.0
30	Presoaked	78.0	8.0	4.0	—	90.0
	Dry	63.5	12.5	7.0	3.0	86.0
Increase for presoaking						4.0

DISCUSSION OF RESULTS

In comparing results obtained from the "R" and "S" methods of germinating sugar beet seed (Table 11), no significant differences were obtained, due largely no doubt to an insufficient number of comparisons required to demonstrate significant differences. Trends were in favor of the "R" method, however. The same was true of the comparisons in Table 2 where the 20° C continuous and the 30° C continuous methods were compared, and the trends were in favor of the 20° C continuous method. Possibly the method adopted by the Association of Official Seed Analysts of North America should be followed, namely, 18 hours at a lower temperature (20° C) and 6 hours at a higher temperature (30° C).

However when all four temperature methods were combined in a statistical analysis (Table 3), a significant difference was obtained between the "R" and "S" alternating temperature and between the 20° C and 38° C temperature methods. The significant interaction obtained in temperature methods versus substrata and moisture treatments indicates that, although temperature methods gave significantly different germination percentages and number of sprouts, respectively, different temperature methods reacted differently with different substrata and moisture treatments. In germination technic, therefore, the temperature method used must necessarily be tested with various substrata and moisture conditions in order to determine the most desirable set of conditions to give the best germination results.

In tests on seed ball size in relation to germination of sugar beet

seed (Table 4), the wide differences obtained in percentage germination and sprout counts (varying directly in proportion to seed ball size) critically indicate the need for thorough mixing of seed, mechanically if possible, to eliminate biased selection of the germination sample. The use of a Boerner grain sampler is essential to the securing of a representative sample. A test conducted on the germination of a specially prepared sample in which a 25-gram sample of seed was made up of percentage amounts by weight of 4.0 mm, 3.5 mm, and 2.5 mm size seed balls, showed this sample to germinate 85.56% compared to 84.88% for the random selected sample. This difference of 0.68% is non-significant. This demonstrates the reliability of the Boerner grain sampler or some other equally effective mechanical device in reducing the beet seed sample to desired size before commencement of a germination test.

To determine minimum length of germination period required for germination of sugar beet seed, a set of 40 samples of seed was germinated in quadruplicate in paper toweling and in sand using the "S" method of alternating temperatures (Table 9). Readings on germinated seed balls and number of sprouts were made on the 4th, 7th, 10th, and 14th day of the test. The results indicate that a period of 10 days is adequate for obtaining reliable germination readings on beet seed. In fact in the case of fresh seed, germinated at a temperature of 30° C, a 7-day period may be adequate under certain conditions (Table 10). In this particular study a 4-, 7-, 10-, and 14-day germination period was used, with sand, soil, and blotting paper as the substrata. Of special interest was the vigor of seedlings in the greenhouse soil test where practically all of the germination was completed at the end of the seventh day. It would seem that for practical field purposes the germination count obtained on most germination tests in the field at the end of 7 days is the important consideration from the standpoint of producing vigorous seedlings of uniform size. Apparently, greater emphasis should be placed on vigor and condition of seedlings, than relying entirely on percentage germination as a sole index of acceptability of seed.

In the conduct of the 336 separate germinations comprising the 84 tests in Series A, three types of substrata, paper toweling, blotting paper, and sand were used. It was found that germination and sprout counts could be made on an average 30% or more faster with either paper toweling or blotting paper as a substratum than when sand was employed. Further, sprout counts were made with much greater ease and accuracy. Also, it was observed that counts could be delayed for a day or two with the paper toweling or blotting paper without entailing too great an additional outlay in time in making the readings. With sand, such delay caused the sprouts to become tangled, necessitating much additional work in making the required counts. In comparing the three types of substrata (Table 5), it is noted that the percentage germination and number of sprouts is practically the same for both the paper toweling and blotting paper and significantly lower for the sand. While the advantage for the two types of substrata is definitely indicated, there is an apparent advantage for the sand method in the

production of somewhat better conditioned and more vigorous sprouts. This is not sufficient, however, to establish its preference over the paper toweling or blotting paper methods.

Forty-two tests each were made with two lots of fresh beet seed, one presoaked for 2 hours prior to germination and the other dry, to determine the effect of pretreatment on germination (Table 6). On this particular lot of seed, no apparent benefit was obtained from pretreatment of seed. However, on beet seed of different ages, a noticeable increase was obtained in rate of germination and percentage increase in germination over dry seed in a test conducted in 1935 (Table 11). It would appear from the experience of these tests that possibly the greatest value in the pretreatment of seed lies in the fact that the substratum can be kept a little drier during the period of the test, the seed starts to swell and germinate more quickly, and molds do not have as favorable a medium in which to multiply, compared to general procedure when dry seed is used for the germination test.

Owing to large differences in quality of water, a study was made of the tap and distilled water used for presoaking the seed in these tests. The results shown in Table 7 indicated no significant difference for either kind of water as used in these tests. Similarly, a study designed to test the effect of these waters on moistening the substratum (Table 8) showed no appreciable difference in favor of one or the other water used in these tests. The conclusion seems warranted, therefore, that under the conditions of this test there was no advantage in using distilled water when tap water was available of the quality described earlier in this paper.

SUMMARY

Tests in quadruplicate were conducted with sugar beet seed to determine effects of variable and constant germinating temperatures, four seed ball sizes, three kinds of substrata, presoaking treatment of seed using tap and distilled water, and 4-, 7-, 10-, and 14-day periods of germination on percentage germination and number of sprouts from representative 100 seed ball samples of seed.

The 20° C continuous method and a method designated as "R" in which was maintained a temperature of 30° C for the first 24 hours alternating with a temperature of 20° C for 16 hours and 30° C for 8 hours for the balance of the test, were productive of somewhat better results than the 30° C continuous method and the standard of alternating temperature at 20° C for 16 hours and 30° C for 8 hours.

Seed ball size was positively correlated with germination. The larger seed balls produced the higher germination and larger number of sprouts.

To secure representative samples, the use of a mechanical grain sampler, such as the Boerner sampler, is necessary.

Paper toweling and blotting paper were found preferable to sand as a germination bed.

No significant differences were obtained for presoaking of fresh seed. On older seed, this treatment appears to have some merit.

Reporting germinating results at the end of a 10-day period seems warranted.

Attention is called to more general consideration of seedling vigor in determining acceptability of seed.

Supplementing germination tests with field tests appears a desirable procedure.

CONCLUSIONS

The results of tests discussed in this paper indicate the need of a random sample of beet seed mechanically reduced to proper sample size; presoaking seed, especially older seed; the choice of either paper toweling or blotting paper; reporting results of tests at the end of 10 days; and supplementing laboratory tests with field tests wherever possible so as to determine vigor of seedling plants. Germinating beet seed at colder temperatures appears desirable. The tentative choice of a 20° C continuous temperature seems warranted by these tests. Further work on this point is necessary to establish the best temperature method.

DIFFERENTIAL FEEDING OF GRASSHOPPERS ON CORN AND SORGHUMS[1]

ARTHUR M. BRUNSON AND REGINALD H. PAINTER[2]

SEVERE outbreaks of insects offer unusual opportunities for studies of their habits, especially in respect to food preferences, and for studies of differential injury between varieties and between related species of crop plants. The grasshopper outbreak of 1936 afforded such an opportunity. The observations presented below are recorded now because of their interest to agronomists and entomologists and because outbreaks offering the possibility of obtaining similar information do not occur with any regularity. Special methods of controlled infestation or trials in localities where grasshoppers are perennially abundant might permit continued and valuable studies.

REVIEW OF LITERATURE

Many agronomists and entomologists think of grasshoppers as a menace to any and all crops, although the literature (1, 3, 4, 5, 6, 8, 10, 11)[3] contains scattered references to the contrary. The 1936 grasshopper outbreak in Kansas was characterized by the wide difference between injury to corn and to sorghums. Such a difference was first noticed by Riley (8) nearly 60 years ago during the early outbreaks of the Rocky Mountain locust and has been mentioned (3) subsequently on a few occasions.

The cause of this preference for corn is unknown but may be a specific characteristic of certain American *Acrididae* since Uvarov (11) records an Asiatic species (*Colemania spharioides* I. Bd) that feeds chiefly on sorghums. It has been shown (7) in the case of some insects that longevity and fecundity are dependent upon specific food plants. It is possible that the decided preference of Kansas grasshoppers for corn and their aversion to the sorghums may be related to their inability to utilize these two plants to equal advantage in metabolism.

MATERIALS AND METHODS

Most of the observations herein reported were made in the yield test plats of the cooperative corn project on the Agronomy Farm of the Kansas Agricultural Experiment Station at Manhattan, Kansas. The different strains of corn were grown in plats two rows wide and ten hills long and each strain was replicated five times in randomized order. Observations also were made in the sorghum nursery at Manhattan and in many farm fields in eastern and central Kansas.

In the corn breeding nursery the grasshoppers were mostly *Melanoplus differentialis* (Thomas) and *M. bivittatus* (Say). Although many grasshoppers were killed by applications of poison bait and by Sarcophagid parasites of the

[1]Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 272 of the Department of Agronomy and No. 452 of the Department of Entomology, Kansas Agricultural Experiment Station. Received for publication January 6, 1938.

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[3]Figures in parenthesis refer to "Literature Cited," p. 345.

adult grasshoppers, enough remained to produce severe injury. No exact count of numbers was attempted, but they were estimated to average about five individuals per stalk of corn. A continual movement of the insects over the field tended to give reasonably uniform distribution. Most of the damage took place over a period of approximately three weeks beginning the first of July.

The percentage of leaf surface destroyed by grasshoppers was estimated independently by three observers for each plat. The average of the three estimates was used as the individual plat figure, so with the five replications of each strain the final value represents a mean of 15 separate estimates. Considering that the three individuals making the estimates worked entirely independently, their readings were remarkably consistent. The mean percentage defoliation recorded by each observer for the 931 plats is as follows: D.A., 19.10; W.H.F., 18.46; R.C.P., 18.21; Mean, 18.59.

The estimates of damage to the Manhattan plats here reported were made during the period July 27–31, 1937. The data obtained were subjected to the analysis of variance (2, 9). Generalized standard errors from the analysis of variance are not shown because of the wide range of means in each table and the tendency toward correlation between means and errors. Further reference to individual standard errors is made in the following detailed discussion.

EXPERIMENTAL DATA

The extreme range of defoliation observed in the experimental corn plats at Manhattan was from 3% to 73%. In the four experiments here reported the range for 122 varieties and hybrids was from 4.0% to 59.8%. As will be shown later in the statistical analyses, there was a significant difference due to place effect in some instances. In general, however, the infestation was reasonably uniform and differences due to location were much less than those due to variety. The variety Pride of Saline occurred in four experiments with slightly different planting dates and located in different parts of the experimental area. In three of these the average estimated injury was 12% and in the fourth 18%. Boone County White occurred in two different experiments, giving average estimated injuries of 22% and 23%, respectively. Within an experiment and often in contiguous plats sharp and consistent differences could be seen between different varieties and strains.

Two types of damage by grasshoppers were evident and each appeared characteristic of certain strains. In the case of Pride of Saline, and certain other varieties and hybrids, the injury consisted mainly of destruction of the tender portions of the leaf blade, leaving the bare midrib. In other strains the grasshoppers cut off the entire leaf at the collar where it is joined to the leaf sheath. Occasionally the pruned leaf was eaten, but in the majority of cases it dried on the ground untouched, while the grasshoppers ate part of the leaf sheath remaining on the plant. The plants within an individual hybrid were more uniform for the type of injury exhibited than were those within an open-pollinated variety. A field of an open-pollinated variety of corn defoliated by grasshoppers and exhibiting both kinds of leaf injury is shown in Fig. 1.

OPEN-POLLINATED VARIETIES

The injury to 16 open-pollinated varieties and strains is shown in Table 1. Four strains of Midland varied from 8.8% to 11.0% defolia-

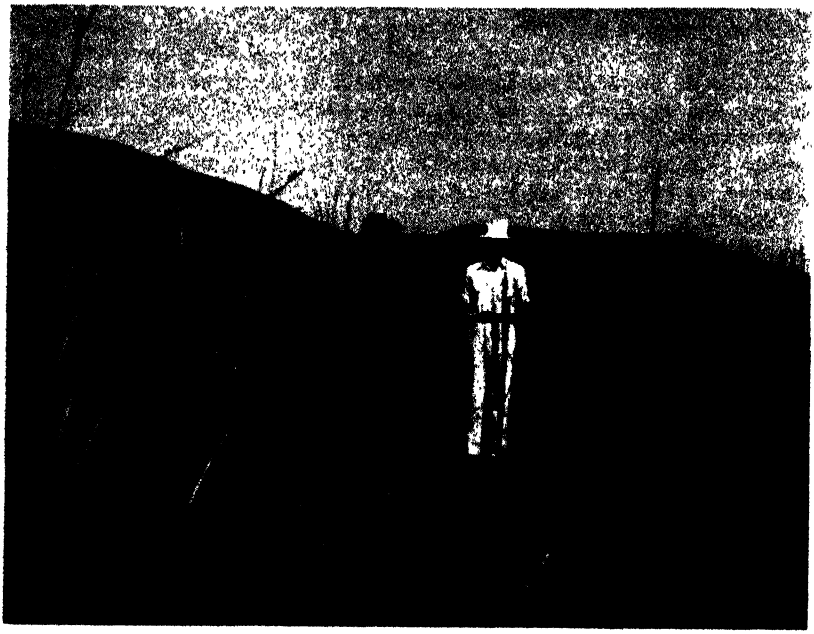

FIG. 1.—Corn field defoliated by grasshoppers. Note that on many plants the sides of the leaf blade have been eaten leaving the midribs intact, while on others the entire leaf has been cut off at the collar and may be seen on the ground.

tion. Five strains of Kansas-grown Reid Yellow Dent varied from 24.0% to 31.4% injury and were the worst injured of the open-pollinated varieties tested. Unfortunately, no unadapted variety from out of the state was represented in this series which probably accounts for the fact that all varieties have fairly low injuries compared with unadapted hybrids listed below. The analysis of variance indicates that the differences between varieties with respect to grasshopper defoliation are highly significant. Standard errors for the individual varieties range from 0.86 to 3.85, although most of them lie between 1.00 and 2.00 and only two are above 2.07. Differences of 5% to 7% in defoliation nearly always indicate significant varietal differences. All strains of Midland are significantly different in grasshopper injury from all strains of Reid Yellow Dent. In this experiment the differences between replications are not statistically significant.

Many fields of open-pollinated varieties of corn exposed to grasshopper injury in the central and eastern part of the state were examined. In all of these fields rather pronounced variation in injury to individual plants was noted. Some plants would be almost completely

TABLE 1.—*Estimated percentage defoliation of open-pollinated varieties of corn at Manhattan, Kansas, in July 1936, each observation being a mean of estimates by three independent observers.*

Rank	Variety	Origin of seed, Kansas county	Days from planting to pollen shedding	Estimated defoliation, %					
				Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	Cassel	Greeley	65	8	7	12	5	6	7.6
2	Hays Golden	Thomas	65	10	8	9	7	5	7.8
3	Midland	Anderson	71	13	10	5	7	9	8.8
4	Colby Yellow Cap	Thomas	65	13	9	8	6	10	9.2
5	Midland	Osage	72	12	11	7	10	7	9.4
6	Muth Red	Mitchell	68	9	6	9	8	15	9.4
7	Midland.	Allen	72	15	6	12	12	7	10.4
8	Midland	Coffey	73	12	12	13	8	10	11.0
9	Yellow Selection No. 1	Chase	72	9	18	13	9	7	11.2
10	Pride of Saline	Riley	72	8	8	15	10	17	11.6
11	Commercial White	Allen	78	22	17	18	23	20	20.0
12	Reid Yellow Dent	Brown	69	22	27	23	30	18	24.0
13	Reid Yellow Dent	Atchison	70	28	30	25	23	22	25.6
14	Reid Yellow Dent	Brown	69	23	30	35	18	30	27.2
15	Reid Yellow Dent	Doniphan	70	32	27	27	28	32	29.2
16	Reid Yellow Dent	Brown	68	38	35	30	37	17	31.4

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total	79	6705.49	—	—	—
Between varieties	15	5652.29	376.82	23.02	Highly significant
Between replications	4	71.93	17.98	1.10	Not significant
Remainder, error	60	981.28	16.35	—	—

defoliated before surrounding plants were severely injured, and at the other extreme, occasional plants would still show little injury when nearby plants were stripped. Photographs of such contrasts in a field of Hays Golden, near Manhattan, are shown in Figs. 2 and 3. In cases

FIG. 2.—A relatively grasshopper-resistant plant in a field of Hays Golden corn showing little injury after surrounding plants had been nearly defoliated.

of only moderate infestation such resistant plants frequently would survive and produce a little seed, but in areas of severe infestation no corn plant was observed which did not eventually succumb.

KRUG TOP CROSSES

In Table 2 are presented the estimated injury to 19 early top crosses together with that of the common pollen parent, Krug Yellow Dent. The inbred parents originated in five states from varieties adapted to local environments. It will be noted that the only two entries from Kansas rank first and third for resistance to grasshopper injury. Here again the analysis of variance shows the differences in grasshopper injury between varieties to be highly significant, but differences between replications to be not significant. Standard errors calculated individually for these top crosses range from 0.24 to 3.52 with nine above 2.00 and four above 3.00. Most differences of 6% to 8% in defoliation are statistically significant.

BOONE COUNTY WHITE TOP CROSSES

In Table 3 are shown the estimated defoliation of a similar series of 32 top crosses from later inbreds, together with two open-pollinated

varieties. The six entries from Kansas inbreds rank 1, 2, 5, 6, 15, and 21 which is appreciably higher than would be expected from a random selection. The analysis of variance indicates that differences between varieties and between replications are both highly significant. The significance is much greater, however, between varieties than between replications. Standard errors of the individual entries range from 0.81 to 5.94 with 10 below 2.00 and 7 above 4.00. In general, differences of 8% to 10% are statistically significant.

FIG. 3.—Variability of individual plants of an open-pollinated variety of corn (Hays Golden) in susceptibility to grasshopper damage. Note the completely defoliated plant in the center as contrasted to the slightly injured one immediately to the left.

HYBRIDS

Table 4 contains the estimated injury for a series of 52 hybrids. Of these, 35 (those whose parent inbreds are designated by PS) originated from Kansas lines. These Kansas hybrids were strikingly resistant to grasshopper injury as compared to most out-of-state hybrids. In contrast, the Iowealth hybrids are grouped at or near the bottom of the list when ranked in order of severity of injury. The analysis of variance shows that differences between varieties and between replications are both highly significant, but, as in Table 3, the significance of differences between varieties is much greater than that between replications. Standard errors of the means of the various hybrids range

from 0.55 to 7.77. In almost all cases differences of 10% to 12% are statistically significant. In the lower ranges of injury (the upper half of the table), much smaller differences are statistically significant because of the smaller errors.

TABLE 2.—*Estimated percentage defoliation of Krug uniform top crosses by grasshoppers at Manhattan, Kansas, in July 1936, each observation being a mean of estimates by three independent observers.*

Rank	Inbred parent	Days from planting to pollen shedding	Estimated defoliation, %					
			Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	Kans. YS 51	67	4	4	5	5	5	4.6
2	Ohio 47	68	4	5	4	12	8	6.6
3	Kans. YS 48	67	4	4	10	8	11	7.4
4	Ind. T 92	67	10	7	7	4	12	8.0
5	Ind. Tr.	66	11	5	8	8	10	8.4
6	Ia. OS 426	67	5	5	10	13	9	8.4
7	Ohio 56	68	16	12	6	15	22	14.2
8	Ia. L289A2	66	8	19	12	16	20	15.0
9	Ind. B_2	67	12	15	17	13	20	15.4
10	Ind. Palin 8	67	15	15	12	18	17	15.4
11	Ill. Hy 8	67	21	13	10	18	20	16.4
12	Ill. 5120	68	21	13	12	20	18	16.8
13	Krug	67	18	13	17	16	20	16.8
14	Ohio 61	68	30	13	15	18	12	17.6
15	Ill. D 8	68	17	20	14	17	27	19.0
16	Ohio 10	67	10	30	20	13	22	19.0
17	Ia 234	66	22	22	18	31	10	20.6
18	Ind. WF9	66	20	23	27	17	23	22.0
19	Ia. $224A_2$	67	28	19	12	30	23	22.4
20	Ia. I 198	66	28	27	17	28	22	24.4

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total	99	5049.36	——	——	——
Between varieties	19	3220.56	169.50	7.87	Highly significant
Between replications	4	191.56	47.89	2.22	Not significant
Remainder, error	76	1637.24	21.54		——

SORGHUMS

Perhaps the most striking contrasts in injury by grasshoppers were observed between corn and sorghums. In only very rare cases was anything approaching commercial damage seen in sorgos or grain sorghums. Adjacent fields of corn and sorghum, in heavily infested areas, invariably showed severe injury to or destruction of the corn, with little or no damage to the sorghum. Such an instance is illustrated in Fig. 4. Isolated sorghum plants growing as volunteers in corn fields remained almost untouched after the surrounding corn was completely stripped. On the other hand, single volunteer corn stalks in fields of sorghum were sought out and destroyed. In areas where both

crops are adapted, such a marked contrast would justify the substitution of grain sorghums for at least part of the acreage of corn in seasons when grasshopper egg counts indicate the probability of a severe infestation.

Observations in a sorghum nursery showed slight but consistent

TABLE 3.—*Estimated percentage defoliation of Boone County White uniform top crosses by grasshoppers at Manhattan, Kansas, in July 1936, each observation being a mean of estimates by three independent observers.*

Rank	Inbred plant	Days from planting to pollen shedding	Estimated defoliation, %					
			Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	Kans. PS 54	75	7	5	4	4	8	5.6
2	Kans. PS 55	76	3	7	7	12	6	7.0
3	Ky. 41	75	8	7	5	9	12	8.2
4	Tenn. 8–6	76	6	5	6	12	13	8.4
5	Kans. YS 55	74	7	9	10	7	13	9.2
6	Kans. YS 53	75	8	8	7	15	9	9.4
7	Pride of Saline	71	12	5	10	12	23	12.4
8	Ind. Tr	72	8	10	10	18	17	12.6
9	Ill. KM 2	74	10	11	12	13	23	13.8
10	Mo. R 104 C	71	13	18	7	27	10	15.0
11	Tenn. 7–6	74	12	8	23	12	20	15.0
12	Ill. R4	72	17	8	15	10	25	15.0
13	Ind. 3 VP	74	17	12	13	23	10	15.0
14	Ohio 47	72	18	12	15	20	18	16.6
15	Kans. YS 58	72	13	15	22	17	17	16.8
16	Ind. Palin 8	72	12	17	28	8	20	17.0
17	Ill. 5120	72	17	18	12	22	22	18.2
18	Ohio 67	71	10	16	27	12	33	19.6
19	Ia. MC 401	71	22	7	18	15	40	20.4
20	Ky. 21	78	28	21	20	15	18	20.4
21	Kans. YS 75	73	23	12	18	20	32	21.0
22	Ind. R 94	72	12	25	23	20	28	21.6
23	Boone Co. White	73	31	22	10	18	30	22.2
24	Mo. J 33 C	74	24	18	27	18	30	23.4
25	Ky. 30a	74	20	12	13	40	37	24.4
26	Ia. L317 C	72	18	20	25	32	32	25.4
27	Ky. 39a	75	27	25	23	27	26	25.6
28	Richey 119–11a	75	37	15	40	32	28	30.4
29	Tenn. JGP 7–2	74	23	20	45	28	42	31.6
30	Ohio 01	69	42	28	40	42	28	36.0
31	Tenn NP 10–1	74	40	27	38	50	30	37.0
32	Ill. Hy	72	28	38	37	32	50	37.0
33	Tenn. 18–4	76	35	28	33	48	42	37.2
34	Ky. 27	74	53	40	43	25	38	39.8

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total	169	21911.11	—	—	—
Between varieties	33	15135.51	458.65	10.68	Highly significant
Between replications	4	1104.32	276.08	6.43	Highly significant
Remainder, error	132	5671.28	42.96	—	—

TABLE 4.—*Estimated percentage defoliation of miscellaneous corn hybrids at Manhattan, Kansas, in July, 1936, each observation being a mean of estimates by three independent observers.*

Rank	Hybrid	Days from planting to pollen shedding	Estimated defoliation, %					
			Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 5	Mean
1	(PS 21×PS 36)×PS 7854	74	3	4	4	6	3	4.0
2	(PS 48×PS 55)×(PS 8×PS 11)	67	5	8	10	5	5	6.6
3	(PS 8×PS 18)×(PS 4×PS 14)	69	6	7	5	10	7	7.0
4	(PS 26×PS 39)×(PS 7852)	74	4	3	13	10	5	7.0
5	(PS 41×PS 54)×(PS 48×PS 55)	65	6	8	5	13	10	8.4
6	(PS 29×PS 36)×(PS 4×PS 14)	70	5	12	13	6	9	9.0
7	(PS 29×PS 36)×(PS 26×PS 34)	71	5	12	7	5	17	9.2
8	(PS 44×PS 54)×(PS 8×PS 17)	67	4	17	7	13	10	10.2
9	(PS 41×PS 54)×(PS 8×PS 18)	67	8	17	8	6	15	10.8
10	(PS 48×PS 55)×(PS 4×PS 14)	67	12	17	8	10	7	10.8
11	(PS 8×PS 11)×(PS 4×PS 14)	68	10	7	9	20	9	11.0
12	(PS 29×PS 36)× PS 34	69	8	22	8	8	12	11.6
13	Pride of Saline×(PS 4×PS 14)	68	12	15	8	10	15	12.0
14	(PS 41×PS 54)×(PS 4×PS 14)	66	7	23	10	8	15	12.6
15	(11b×61)×(23×24)	73	6	20	14	13	11	12.8
16	(PS 10×PS 17)×(PS 4×PS 14)	66	15	18	8	7	17	13.0
17	(PS 44×PS 54)×(PS 4×PS 14)	67	7	12	15	18	13	13.0
18	(PS 10×PS 18)×(PS 4×PS 14)	67	8	22	18	8	10	13.2
19	(PS 5×PS 18)×(PS 4×PS 14)	68	7	20	13	13	15	13.6
20	(PS 8×PS 17)×(PS 4×PS 14)	67	20	15	13	8	12	13.6
21	(PS 41×PS 55)×(PS 48×PS 51)	64	5	10	17	15	25	14.4
22	(PS 48×PS 51)×PS 55	67	20	7	15	8	25	15.0
23	(PS 24×PS 39)×(PS 4×PS 14)	68	4	28	13	15	18	15.6
24	(PS 6×PS 18)×(PS 4×PS 14)	67	8	22	30	11	8	15.8
25	(PS 41×PS 55)×(PS 8×PS 11)	67	12	13	27	20	15	17.4
26	(PS 5×PS 11)×(PS 4×PS 14)	68	12	11	22	15	28	17.6
27	(PS 10×PS 11)×(PS 4×PS 14)	64	7	18	30	15	18	17.6
28	Pride of Saline (Open-pollinated)	69	8	27	12	13	30	18.0
29	(PS 41×PS 55)×(PS 10×PS 17)	63	13	23	18	13	28	19.0
30	(PS 41×PS 55)×(PS 5×PS 19)	66	15	18	17	20	28	19.6

31	(PS 41×PS 53)×(PS 8×PS 18)	68	13	23	30	17	20	20.6
32	(11 a×61)×(23×24)	69	14	14	27	28	20	20.6
33	(PS 41×PS 53)×(PS 4×PS 14)	67	15	30	20	23	22	22.0
34	(11 a×23)×(41×43)	71	13	30	21	35	15	22.8
35	(PS 5×PS 19)×(PS 4×PS 14)	67	13	23	35	27	25	24.6
36	(11b×23)×(41×43)	71	22	13	28	28	33	24.8
37	(PS 48×PS 51)×(PS 10×PS 17)	64	18	32	25	20	32	25.4
38	(PS 48×PS 51)×PS 11	64	27	38	20	25	23	26.6
39	(PS 5×PS 18)×PS 7844	69	13	17	40	40	38	29.6
40	(PS 41×PS 53)×PS 11	65	22	32	38	32	37	32.2
41	Iowealth Hybrid D	64	32	27	58	30	28	35.0
42	Iowealth Hybrid 3594	66	23	37	52	42	33	37.4
43	Iowealth Hybrid CR	67	40	38	47	35	28	37.6
44	(A×L)×(Hy×R4)	64	25	45	48	28	42	37.6
45	(A×Tr)×(R4×Hy)	67	45	48	28	42	35	39.6
46	(A×L)×(I 234×I 289)	61	47	35	52	48	42	44.8
47	Iowealth Hybrid CC	65	60	48	32	48	38	45.2
48	Iowealth Hybrid CI	62	62	45	57	38	47	49.8
49	Iowealth Hybrid AQ_2	65	45	75	60	33	37	50.0
50	Iowealth Hybrid CX	64	48	50	52	42	62	50.8
51	Iowealth Hybrid A_2	62	57	57	60	43	43	52.0
52	Iowealth Hybrid C	63	70	52	57	57	63	59.8

Analysis of Variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Significance
Total	259	62,832.69	—	—	—
Between varieties	51	51,284.29	1,005.57	19.79	Highly significant
Between replications	4	1,181.52	295.38	5.81	Highly significant
Remainder, error	204	10,366.88	50.82	—	—

FIG. 4.—Adjacent fields of sorghum and corn. The sorghum plants (left) are scarcely touched while the corn plants (right) are rapidly being defoliated.

differences in grasshopper injury to different varieties. In general, injury to the sorgos and the kafirs was less than to milo and to some of the newer varieties originating from hybrids involving milo.

DISCUSSION

The striking contrasts in defoliation recorded in Tables 1 to 4 and the consistency of injury to individual hybrids or varieties in the various replications leave little doubt of a genetic basis for the differential injury recorded. Two other hypotheses, however, might be considered as possible explanations of the differences in injury to individual plants and strains of corn. It is known that grasshoppers tend to be gregarious, feeding on parts of the plants where sap is exposed by the feeding of other grasshoppers. While this habit may explain why certain plants escape in a general field, it will not explain the occurrence of consistent differences between strains occurring through several replications. A second possible explanation might be based on differences in maturity of plants. Although it was noticed that two plantings of the same corn on different dates sometimes differed in the amount of injury by grasshoppers, no consistent relationship between injury and time of flowering of strains planted at the same time could be found. Except in the open-pollinated varieties, as shown in Table 1, comparatively small differences in flowering dates were represented in any one test. It is the opinion of the authors that neither the gregarious instincts of the grasshoppers nor differences in maturity of the tested strains was of importance in determining the differential injury noted. Heritable differences in resistance to grasshopper injury may be worth consideration in corn improvement programs in regions which have frequent grasshopper outbreaks.

The Kansas inbred lines involved in the top crosses and hybrids reported on have come from varieties adapted to a grasshopper-infested environment where occasional severe outbreaks have been experienced. Under these conditions and with the variability in corn illustrated in Figs. 2 and 3, it would seem reasonable to assume that natural selection has operated to eliminate the variants most susceptible to grasshopper injury and to favor the propagation of local varieties from the most grasshopper-resistant individuals. Complete immunity has not been attained, it is true, but rather striking differences have been developed. Neither has complete immunity from the harmful effects of high temperature or of insufficient moisture been attained, but the hardy varieties of corn from the southwestern Great Plains can endure these severe conditions much better than the varieties native to Iowa or Illinois. Adaptation to environment in naturally cross-fertilized species is the gradual and cumulative result of natural selection, and it seems entirely reasonable to assume that it may include in many cases the building up of resistance to native insect enemies.

SUMMARY

1. In the grasshopper outbreak of 1936 outstanding instances of differential injury among corn varieties, top crosses, and hybrids were noted. In one series of 52 hybrids, defoliation ranged from 4.0% to 59.8% as averages of five randomized replications.

2. Extreme contrasts between grasshopper injury of corn and of sorghums were noted. In some cases corn in one field was eaten to the ground while sorghum in an adjacent field was practically uninjured. Although all sorghums show considerable resistance, the sorgos and kafirs were injured less than milo and milo derivatives

3. As a rule, the varieties and inbred lines of corn showing the greatest resistance originated in areas where grasshoppers are a natural element of the environment. It is suggested that natural selection operating in the development of adapted varieties of corn has tended to intensify resistance to grasshoppers and to other natural insect pests of the region.

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NOTES

A DWARF OAT FOUND IN A NOTEX-VICTORIA CROSS[1]

AN interesting dwarf oat plant was found in 1934 in a mass hybrid planting in the sixth generation of the cross, Nortex x Victoria, at Texas Substation No. 6, Denton, Tex. The cross was made by F. A. Coffman, Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

FIG. 1.—Rows of Victoria oats (left), dwarf (three center rows), and Nortex (right).

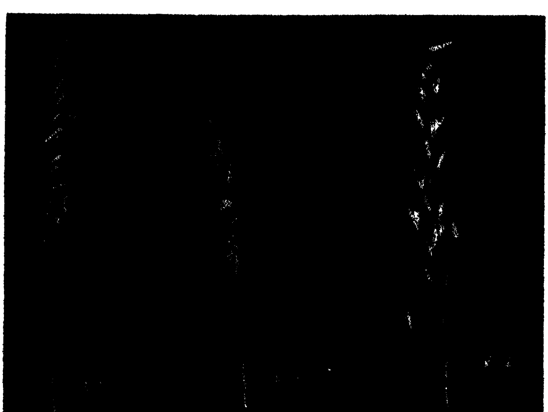

FIG. 2.—Panicles and spikelets of Nortex (left), dwarf oat (center), and Victoria (right).

The dwarf strain has been grown three seasons and continues to breed true. The dwarf plants (Figs. 1 and 2) are about half the height of Nortex, the shorter of the two parents. The culms are rather thick, stiff, and strong; the panicle is very short and compact; the florets are short and plump, with outer glumes frequently wanting; awns are very short and weak, or absent, in contrast

[1]Technical Series No. 446, Texas Agricultural Experiment Station.

to the rather long, prominent awns of both parents. The dwarf strain is moderately resistant to crown rust, although not so resistant as the Victoria parent. It has not been tested for resistance to smut.

Although several attempts to cross this strain with other oats have been made by Mr. Coffman, no seed has been obtained. Additional attempts will be made to cross it on normal oats. It may possibly be of value in breeding to reduce plant height and awn size and to improve the strength of stem.

In panicle and spikelet characters this dwarf oat somewhat resembles the so-called "Trelle dwarf" reported by Derick.[2]—I. M. Atkins, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture,* and P. B. Dunkle, *Texas Substation No. 6, Texas Agricultural Experiment Station.*

[2]Derick, R. A. A new "dwarf" oat. Sci. Agr., 10: 539–542. 1930.

GUMMED-PAPER TAPE FOR SPACE-PLANTING WHEAT

A METHOD is described for space-planting wheat or other small grains by the use of a contrivance for placing the seeds at desired intervals on gummed-paper tape before seeding time. The rolls of tape are planted with a New Columbia Planter using a simple spool and shoe attachment. The necessary materials usually may be found around any agronomy department or purchased for less than $10. Plans for this planting method were developed after consultation with W. J. Sando of the Division of Cereal Crops and Diseases and Olaf Gronaas of the North Dakota Agricultural Experiment Station.

Garden seeds glued to a "seed tape" have been on the market for more than 20 years. The machine used in applying the seeds to the glue-coated tape, however, was not adapted to the small numbers of seeds planted in individual nursery rows, and a machine for planting the tape was not available.

Space-planting of seed often is necessary where the mature plants are to be separated and studied individually. It is also useful when the number of seeds is limited and maximum yield per plant is required. The quantity of seed that can be space-planted ordinarily is limited by the time and help available for dropping individual seeds by hand. A stand supporting a planting board with holes bored at suitable intervals for dropping individual seeds into the furrow has eliminated stooping but has not been usable in windy weather, and even under optimum conditions two men could plant only about 30 17-foot rows per hour. A cylinder for the Columbia planter with small shallow holes can be used to plant rapidly 70 to 80 kernels per row if the seeds are of uniform size, but often two seeds fall together in the row, and satisfactory separation of the plants at harvest is not possible.

Probably the most satisfactory solution of the problem has been presented by Vogel[1] who used a drill with a seed cup having a conical center turning in a horizontal plane. The kernels fall into individual

[1]Vogel, O. A. Three-row nursery planter for space and drill planting. Jour. Amer. Soc. Agron., 25: 426–428. 1933.

pockets in the bottom of the cup and any extra kernels are swept off by a brush riding above the opening at the moment of dropping through. When the seed is of uniform size, Vogel's drill is preferable to gummed paper because it requires less labor. This drill, however, is unsuitable in the durum wheat breeding program at Fargo, where several different kernel types and shapes are involved and where rust and heat have caused many strains to be more or less shriveled.

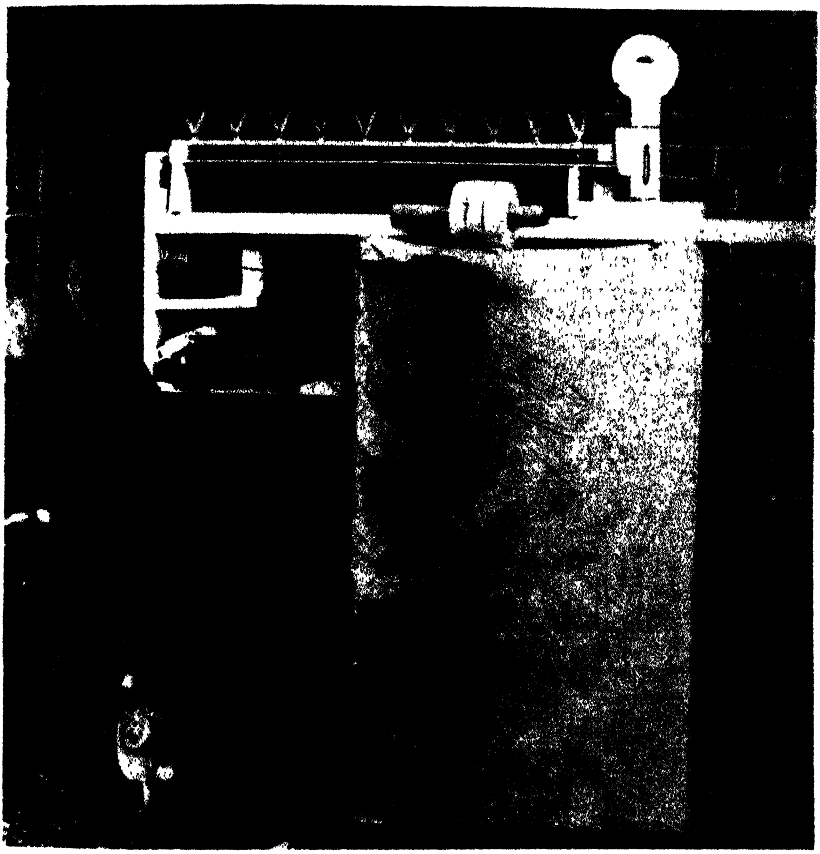

FIG. 1.—"Tape spacer" and New Columbia Planter with space-planting slide and spool attached. Also ¾ roll of toilet tissue on spindle after having been cut on wood lathe.

The tape-spacer for sticking the seed on gummed 1-inch tape is illustrated in Fig. 1. A half-turn of the crank moistens a 30-inch strip of tape and a kernel is then dropped through each of the 10 funnels onto the gummed paper. The machine then covers the kernels with a one-inch strip of toilet tissue, presses the tissue and gummed tape together, and rolls up the strip usually into 17-foot lengths.

A drawing of the tape-spacer is shown in Fig. 2. This drawing differs from the photograph in Fig. 1 in that the tape moistener has

been placed nearer the funnels so all the tape under the funnels at one time is freshly wet.

The gummed-paper roll is held in an ordinary moistener stand, but instead of the metal roller ordinarily used for gummed tape, an office letter moistener consisting of a small brush inverted in water contained in a small metal dish is used to effect more uniform moistening. The tape passes around a spool which turns the gummed side up so that the kernels can drop through the funnels onto the sticky surface. The kernels are sealed in position by the toilet tissue which is pressed against the gummed surface in passing between two rollers covered with sponge rubber weather stripping. Tension on the rolls is main-

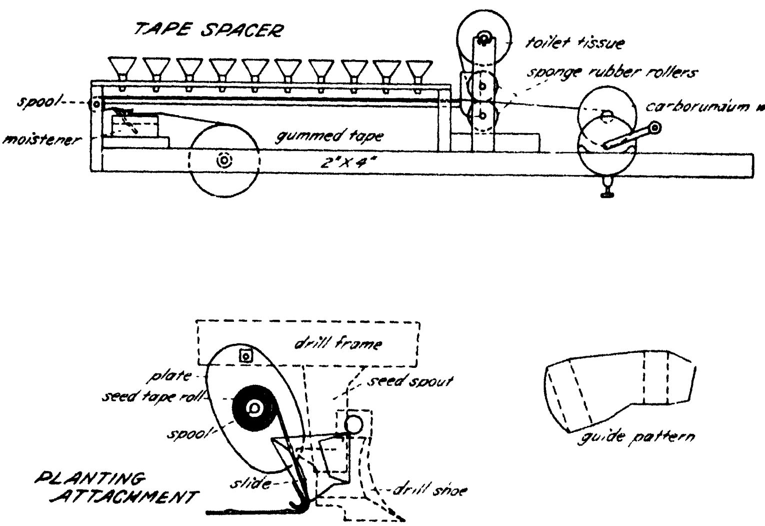

FIG. 2.—Design of "Tape spacer" for dropping spaced seeds and rolling up gummed tape. Also planting attachment for use with New Columbia Planter. Regular drill parts are dotted in.

tained by rubber bands between ¼-inch bolt axles. The tape is rolled up on a 1-inch composition bottle cap (from a mouth-wash bottle) fastened by a nut to the shaft of an ordinary hand-turned carborundum wheel. Although a cheaper winding device might be made, such a grinder usually is available, and has the advantage of being geared so that half a turn of the handle is sufficient to wind 30 inches of tape. A wire (straightened paper clip) is attached to the shaft and bent outward along the face of the spool roller, and the folded end of the tape is hooked to this wire before starting the winding. The base of the tape-spacer is made of 2- by 4-inch lumber.

When 3-inch spacing is used, 10 seeds are dropped and rolled up at a time, making seven sections for a 17-foot row. If more than 30 inches of tape is wet at a time, the adhesive dries before the seeds can be covered. One-inch tape is preferable to greater widths because it is easier to cover in the furrow, while a tape narrower than 1 inch will

not hold the kernels satisfactorily. Spacings other than 3 inches may be used by making appropriate funnel stands.

Each rolled tape is pulled off the roller, the row number stamped on, and the end fastened with a paper clip. About 18 inches of blank tape are left at the numbered end for holding onto when starting to plant. A red pencil mark near the last kernel permits the ends of the rows to be kept in line.

The planting device, also illustrated in Figs. 1 and 2, consists of a free-turning spool attached to the frame, and a metal guide attached to the drill spout of a New Columbia Planter. The spool turns on a bolt attached by nuts to a heavy tin guard or plate, made from a large sardine can, which is bolted to the drill frame. The spool is tapered toward the outer end so as to receive the roll of tape readily. An empty adhesive tape spool held against the spool by rubber bands prevents the tape from flying off the spool as it unrolls. The guide which directs the unrolled tape into the furrow was cut from heavy galvanized iron. It hooks around the seed spout of the Columbia planter and is held by tightening the thumb screw of the regular drill shoe which fits over the guide and seed spout. The lip of the guide is bent around down and back to avoid cutting the paper and is close behind the drill shoe so the tape is placed in the bottom of the furrow before the soil falls back to cover it. The guide is open on the outer side so the tape may be slipped into place quickly. To load the drill for planting, one man raises the handles and the other holds back the spool cover, slips the tape over the spool, unrolls about 2 feet, and slips the tape over the guide. In planting, he holds the end of the tape so that the red mark indicating the first kernel matches the beginning of the row while the first man starts the drill and then lets go of the tape after 2 or 3 feet are covered with soil. At Fargo, where the soil is heavy, discs from the Planet Jr. cultivator outfit are attached to the Columbia planter for all nursery planting in place of the regular covering device.

The tape is planted with the tissue side up. The damp tissue offers practically no resistance to the emergence of the germinating seedlings.

Tissue in unperforated rolls 1 inch wide could not be purchased, so ordinary toilet tissue rolls (4½ inches wide) were cut into four sections. Certain brands with light perforations were most satisfactory. A slightly tapered wood spindle (Fig. 1) which fitted tightly into a roll of paper was made in a wood turning lathe. A roll of tissue is placed on the spindle so that when turned in a lathe it will tend to wind up rather than unroll. The spinning roll is marked into four sections each 1⅛ inches wide with a soft or wax pencil, and then cut with a sharp butcher knife. It is necessary to work from the back of the lathe with the roll turning away from the knife so it will cut straight. The lathe should be run at the slowest speed. The four narrow rolls of tissue will cover 60 to 70 17-foot rows of tape. The ordinary rolls of gummed paper are long enough for about 40 rows of tape.

The total time required for the gummed-tape method of space-planting is about the same as that with the old method of direct hand planting, but about three-fourths of the work may be done inside and

during the winter. The tape-spacing operation may be done by two men at the rate of 35 to 40 17-foot rows per hour, and planting in the field by two men is accomplished at the rate of 100 to 150 rows an hour. The tape rolls may be planted in any weather when ordinary planting can be done. Planting with the Columbia planter using the regular cylinders may be done without detaching the spool and tape guide.

Wheat space-planted with gummed tape in 1936 and 1937 showed no indication of having been injured by the tape. However, one precaution must be observed. The tape must be covered more carefully in wet heavy soil than in ordinary planting. Evidently this is because of air spaces left which dry out the tape and prevent germination. If the soil is crumbly enough to pack well so that the tape is in direct contact with moist soil, no difficulty should be experienced. The paper soon rots in the field.

Aside from the advantage of speed, the tape method does not leave an open furrow exposed to drying air which frequently causes difficulty in obtaining uniform emergence by hand planting.—GLENN S. SMITH, *Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture.*

CONSTRUCTION OF A DURABLE PASTURE CAGE

SMALL cages are widely used for making herbage yield determinations in a pasture that is being grazed. These cages must be light in weight so that in the field they may be easily moved, yet durable enough to prevent damage by the grazing animals. A cage that is both light and durable and that has been proved satisfactory by a season's use, is described here.

Most investigators in determining herbage yields use a cage that is 3 or 4 feet square. This often results in an extremely small yield of herbage from each plat. Mechanical errors of mowing or weighing,

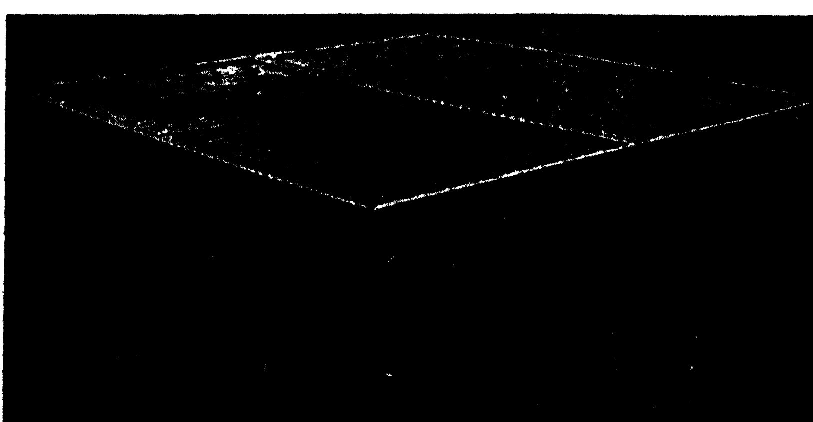

FIG. 1.—Cage assembled for field use.

which may occur when these plats are mowed with a power mower, will be greatly magnified if the yields are expressed on an acre basis. By increasing each side of the cage two-fold, the area harvested will be four times as large and the mechanical error from mowing will be

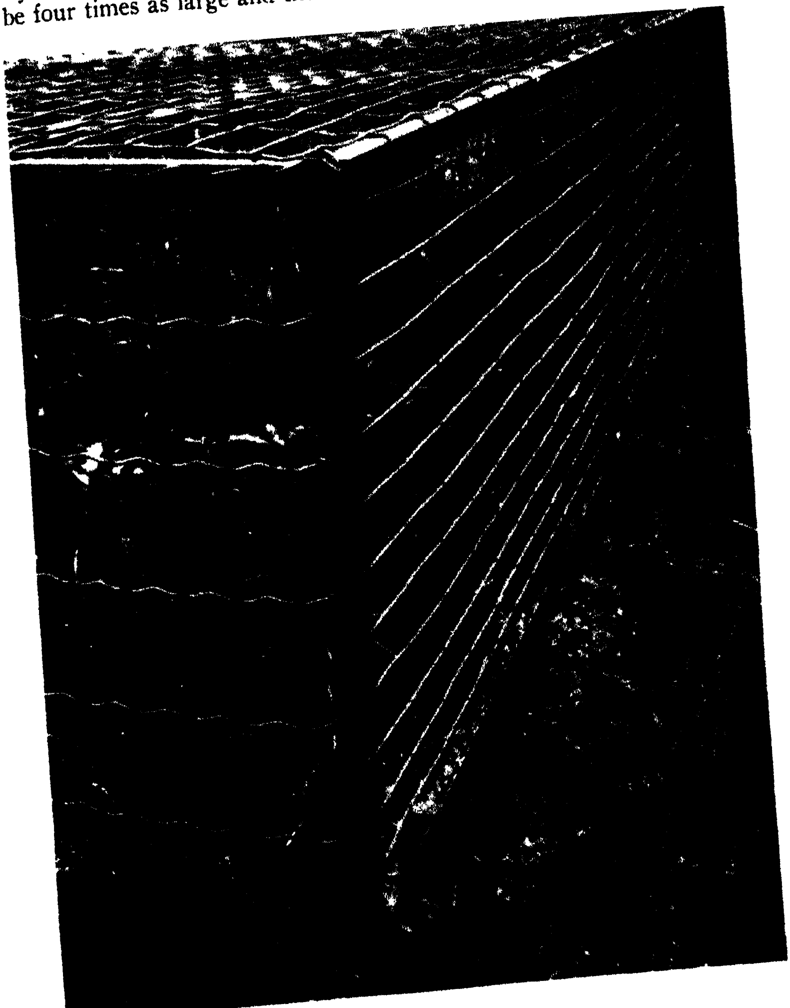

FIG. 2.—Method of staking down the cage.

reduced in proportion to the total herbage yield. For this reason the cages were constructed 8 feet square (Fig. 1). Cages of this size can be easily moved in the field and the increased size does not necessarily mean a reduction in the number of replications.

The framework of the cage was 1 inch x 1 inch x 1/8 inch black angle iron and painted with a lead paint. To facilitate transporting, each side

was made in a single section and the sections assembled and covered with wire in the field. Each section was made of welded angle-iron and the four sections bolted together at the corners to form the framework of the cage. One angle-iron brace was placed across the top of

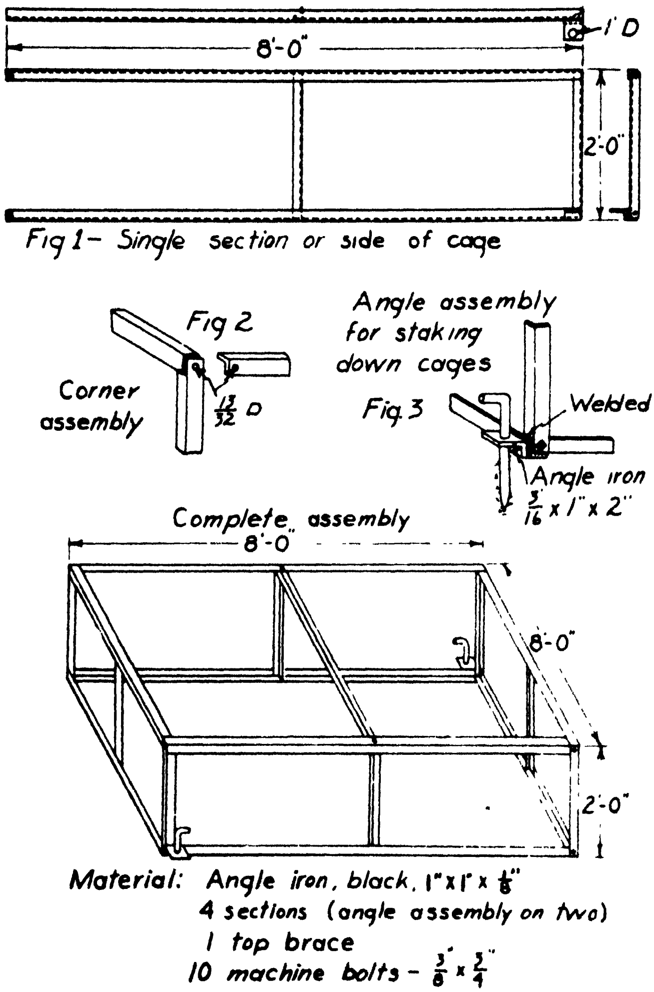

FIG. 3.—Diagram showing construction of framework for cage.

the cage for additional bracing and to prevent the sides of the cage from being pulled together as the wire was stretched onto the frame. It also prevents the wire on the top of the cage from sagging. For staking down the cage a small angle-iron with a 1-inch hole was welded onto the framework at opposite corners of the cage (Fig. 2). Detailed construction of the framework is shown in the accompanying diagram (Fig. 3).

The cages were covered with electric weld, galvanized, woven wire, with horizontal and vertical wires size 11, and with mesh 2 inches x 4 inches. The heavy gauge wire was used to prevent grazing animals from tearing the wire by rubbing or by hooking it with their horns. The electric weld gives added bracing and prevents the wire from sagging between the places where it is fastened.

The construction cost of the cage framework was $6.50 each. This included the materials, bolts for assembly, and one coat of lead paint. Cost of the electric weld wire as described was $3.75 for each cage. A lighter weight wire may be purchased at a lower cost. To these costs must be added the labor cost of assembling the framework and attaching the wire.—J. M. POEHLMAN, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture and Missouri Agricultural Experiment Station.*

SPINELESS CACTUS WINTERKILLS IN MONTANA

IN the search for plants that may prove of value in range reseeding or for emergency forage in Montana, some species are tried even though the probability of success is not very high. In April 1934, Superintendent W. H. Dameron of the Texas Agricultural Experiment Station substation at Sonora, Texas, kindly shipped for trial three sacks of vigorous-appearing internodes of a spineless cactus (*Opuntia ellisiana* Griff.)[1] to Miles City, Montana. These were planted at the U. S. Range Livestock Experiment Station[2] on April 24 in a previously dry-farmed field located adjacent to the Yellowstone River, but since used for range reseeding trials with a minimum of soil cultivation. A slit in the fine sandy-loam soil was opened with a spade, individual cactus "slabs" were inserted at varying inclinations, and the soil firmed back to cover the lower half of the cactus.

With only 5.51 inches of precipitation during the year, 3.53 inches of which occurred in the April-September period, 1934 proved to be the most severe drouth year in more than half a century of weather records at Miles City. Before the end of May, some growth was noted on about 10% of the slabs. Despite drouth, extreme heat, and the absence of soil cultivation, several of these slabs bloomed and more than half of them made some growth during the season and produced one to five new internodes each. Growth was noted during June and July when lack of available soil moisture forced most native range species into dormacy. Results of examinations on August 23 and November 2, 1934, are summarized in Table 1.

TABLE 1.—*Results of tests of Opuntia ellisiana, 1934.*

Number internodes planted	Number showing recent growth		Number blooming before	Number destroyed by rodents, cattle, etc., before		Number clearly dead on	
Apr. 24	Aug. 23	Nov. 2	Aug. 23	Aug. 23	Nov. 2	Aug. 23	Nov. 2
166 100%	67 40.4%	84 50.6%	22 13.3%	3 1.8%	21 12.7%	32 19.3%	35 21.1%

Between April 24 and November 2, the lowest temperature recorded at Miles City was 23° on November 1. Minimum temperature ranged from 24° to 30° on the five preceding days. The cactus appeared to have survived this frosty weather with little damage. About two-thirds of the total number were covered on November 2 with a straw mulch to a depth of 5 to 8 inches for winter protection. On

[1]Identified by Range Botanist V. L. Cory of the Sonora, Texas, Substation. Mr. Cory reports that the species "flowers and sets fruit quite abundantly but so far as we know never produces viable seed." He suspects it may prove to be "a lethal mutation of *O. lindheimeri* Englm.," the predominant cactus of the Rio Grande Plains.

[2]Range research work is conducted here by the Northern Rocky Mountain Forest and Range Experiment Station of the Forest Service in cooperation with the Bureau of Animal Industry and the Montana Agricultural Experiment Station.

November 26, 1934, it was noted that many of the exposed cactus internodes were frozen hard and had a thin coating of ice, while straw-covered internodes were pliable. The lowest temperature between November 2 and 26 was 21°, which was preceded by four days with minimum temperatures ranging from 22° to 29°. All uncovered cactus plants were apparently damaged or killed by this period of frosty weather.

Two or three of these spineless cactus slabs were potted and taken inside a residence during the winter. These were still thriving during the summer of 1937.

In late April 1935, all plants in this field, both exposed and covered, were found to be reduced to a soft lifeless mass of greenish gray pulp. It is apparent that this spineless cactus from Texas cannot survive eastern Montana winters where temperatures down to minus 30 and 40 degrees occasionally occur. Unless a more cold-resistant variety is developed to withstand such temperatures, Montana will be unable to benefit from the remarkable productiveness as reported from Texas of this source of emergency range forage.—LEON C. HURTT, *Northern Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, Missoula, Montana.*

A LABORATORY FOR SEDIMENTATION STUDIES

A LABORATORY designed to test the sediment-load of streams has been built by the Works Progress Administration of North Carolina across Rocky Creek in Iredell County for the Dept. of Agriculture. Sedimentation studies will be the aim of the Soil Conservation Service work at this station.

Spanning the stream, 14 concrete veins spaced 5 feet wide adjoin concrete and stone revetments. Four feet below each section is a 16-inch pipe, leading to a pump house. Hydraulic oil cylinders permit a sample of each or any vein to be pumped into the vats.

FIG. 1.—Construction for sedimentation studies on Rocky Creek in Iredell County, North Carolina

Qualitative and quantitative analysis of the samples will be made to determine from the suspended load what bed load of sediment is carried by the stream under all conditions.

North Carolina, immense developer of water power, has a vital interest in the experimentations which aim to find out how to prevent depletion of reservoir capacity; to determine the life of a reservoir by finding out exactly what went into it after each rain; the relationship between the sediment load and hydraulic functions of a stream; how much damage is being done to land on a particular watershed and how much would be justifiable to spend in a particular section to control soil erosion and the best method to adopt for that purpose; conservation of navigability of streams; and the prevention of flood damage.

Similar devices are being installed at Greenville, South Carolina, and Dadeville, Alabama.

AGRONOMIC AFFAIRS

STUDENT SECTION ESSAY CONTEST

THE American Society of Agronomy will again sponsor a Student Essay Contest. The Chicago Board of Trade has donated considerable financial assistance to make it possible to grant rather large rewards for outstanding papers. Students presenting the best papers will receive awards as follows:

The first three winners will receive expense money to enable them to attend the International Grain and Hay Show in Chicago, the total allotment for the three not exceeding $150.00. The amounts granted will vary with the distance the winners are from Chicago. For example, if a Wisconsin student won first and an Oregon student second, it would be desirable to grant a larger amount to the Oregon student as his expenses would be greater. The committee reserves the right to adjust this as conditions warrant. In addition, the three high men shall receive appropriate medals and a year's subscription to the JOURNAL of the American Society of Agronomy. The winners of the fourth, fifth, sixth, and seventh places will receive cash awards of $20, $15, $10, and $5, respectively.

All essays must be prepared by undergraduate students. Students graduating during the course of the 1937–38 school year or those graduating during the summer school of 1938 are eligible, providing their papers are submitted before graduation. A certification of eligibility to qualify as an undergraduate, signed by the dean of the college, must accompany each paper.

Papers should be typed, double spaced, and should not exceed 3,500 words in length. *An abstract of not more than 500 words must accompany each paper.* Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify the paper.

The title for the essay shall be "Contributions of Agronomic Research to Agricultural Progress."

It is suggested that students may choose to develop the subject either from the viewpoint of crops or soils, or of both, and may draw upon those fields for specific examples.

The committee suggest that where several papers are entered from a given institution, the local representative of the Society review the essays and submit only the best articles. This will save work for the committee and reduce mailing expenses.

Essays must be in the hands of the Chairman of the committee, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than October 1, 1938.

SPECIAL MEETING OF SECTION V, SOIL SCIENCE SOCIETY OF AMERICA

A SPECIAL meeting of Section V of the Soil Science Society of America was held at Knoxville, Tenn., April 8 and 9 primarily for the purpose of a conference of Soil Survey field men working in the various counties in the Tennessee Valley area. All persons interested in soils and agricultural work in general were invited to participate in the discussions.

Three general sessions were held with Messrs. W. E. Hearn, S. S. Obenshain, and L. R. Schoenmann acting as chairmen and with a number of papers on a wide variety of topics. W. M. Landess opened the conference with an address on "Happy Lands" and Dr. C. E. Kellogg discussed "The Relationship of Scientific Classification of Soils to Problems of Applied Soil Science". The second afternoon was devoted to a session for federal and state administrative officials and a special period for a discussion of field problems by field men in attendance with W. E. Hearn presiding.

The meeting was brought to a close with a banquet on the evening of April 9 with Prof. T. B. Hutcheson of Virginia Polytechnic Institute as toastmaster and the Hon. H. L. Brown, Assistant Secretary of Agriculture, as guest speaker.

SUMMER MEETING OF SOUTHERN SECTION OF SOCIETY

THE summer meeting of the Southern Section of the Society will be held in Alabama from August 8 to 12, under the auspices of the Agronomy and Soils Department of the Alabama Polytechnic Institute. An automobile tour through the state has been arranged for the purpose of visiting substations and experiment fields and the station at Auburn. Southern agronomists and agronomists outside the southern area are especially invited to participate. For further details, communicate with Dr. J. W. Tidmore, Department of Agronomy and Soils, Alabama Polytechnic Institute, Auburn, Ala.

NEWS ITEMS

DR. J. W. TURRENTINE, President of the American Potash Institute, Inc., Washington, D. C., has been awarded the gold medal of the Academie d'Agriculture de France for the collaboration of the Institute in the preparation of the book on "Potash Deficiency Symptoms" recently published in Berlin.

A MEETING of the Alfalfa Improvement Conference will be held at Manhattan, Kansas, June 24 and 25, immediately following the meeting of the Corn Belt Section of the American Society of Agronomy in Missouri.

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LOSSES OF PHOSPHATE FROM A LIGHT-TEXTURED SOIL IN ALABAMA AND ITS RELATION TO SOME ASPECTS OF SOIL CONSERVATION[1]

GEORGE D. SCARSETH AND W. V. CHANDLER[2]

THE problem of supplying crops with phosphate is very important because most soils, especially those of the humid South, are deficient in available phosphate. Furthermore, phosphates added in fertilizers are soon made unavailable by being fixed into insoluble forms by components in the colloidal fraction of the soil (5),[3] and it is generally believed that these fixed phosphates accumulate in the soil profile.

Several investigators (2, 3, 4, 6, 7, 8) have reported that slight amounts of phosphates have moved into the lower layers of the soil, but they believed this movement to be chiefly mechanical. Obviously, the greatest residual accumulation should then be in the upper soil layers. Undoubtedly, this accumulation should be of considerable extent in heavily phosphated fields in climates where winter erosion is slight, or where the vegetative cover is heavy throughout the year; but in the light-textured, clean-cultivated soils of the humid South, where erosion is great throughout the year, the accumulation is likely hindered. Where erosion removes the topsoil to plow depth every few years there can be no accumulation of phosphate. Where the land lies nearly flat, erosion does not remove a great volume of soil, and only muddy water, colloidal suspension, runs along the furrows in the middles and away. Since this type of erosion does not deface the appearance of the field, it is generally not considered extremely important to the farmer. Almost no data exist to indicate what the phosphate losses are in the small amount of colloidal material that is lost from soils that are considered not to be seriously eroded.

An opportunity to study the movement of residual phosphate in a loamy sand (Norfolk) that had received various kinds and amounts

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of Director. Received for publication January 26, 1938.

[2]Associate Soil Chemist and Graduate Assistant, respectively. Senior author Soil Chemist, Purdue University Agricultural Experiment Station, Lafayette, Ind., since February, 1938.

[3]Reference by numbers in parenthesis is to "Literature Cited," p. 374.

of phosphate fertilizers and on which crop yield records had been obtained for a period of 26 years existed in the Cullars rotation experiment on the Alabama Experiment Station farm at Auburn, Alabama.

The object of this paper is to report the results of a study of the phosphate situation in the soils of this experiment and to interpret the significance of these results as they relate to the problem of maintaining an adequate supply of available phosphate in soils and to the conservation of soils.

DESCRIPTION OF CULLARS ROTATION EXPERIMENT

This field experiment was started in 1911 by M. J. Funchess on a Norfolk loamy sand and has for its purpose the studying of the effects of legumes as soil improvement crops in a 3-year rotation of cotton, corn, and oats. The test contained three tiers, each with 14 1/20-acre plats, but only a few of these are involved in the study reported here. A more detailed description of the experiment is published elsewhere (1, 9).

The fertilizer treatments on the plats studied, the total amount of P_2O_5 added in the 26-year period, and the average annual yields of the three crops as shown in Table 1. The rate of application of the phosphates was not uniform throughout the period; therefore, only the total amount of P_2O_5 added is given. This figure was obtained by assigning the total P_2O_5 content of superphosphate at 18% and that of the rock phosphate at 32%. The yield data will be discussed later when other factors are presented.

METHOD OF SAMPLING AND MECHANICAL COMPOSITION OF SOIL

Since the phosphate fertilizers were added in narrow strips in the row, it was necessary to composite the topsoil samples by taking a cross-section of the soil across the rows and middles. This was done by taking 8- by 1-inch cores every 6 inches across the entire plat on each tier. Each composite sample contained 180 such cores. The subsoil samples were taken from the row at consecutive 8-inch depths to 56 inches and each sample for any horizon was composited from three locations on corresponding plats from each of the three tiers.

The mechanical composition was determined on each sample and since the soils showed a fair uniformity, the data are presented from one plat only, *viz.*, plat 5. The clay content of the soil and a diagrammatic interpretation of the data with regard to the movement of the clay fraction away from or into the soil column is given in Fig. 1. Since data are not available on what the clay content of this soil would have been without any movement of the clay, the results cannot be accurately analyzed; however, some assumptions seem obvious. Horizon 1 (0–8 inches) contains less clay than any other horizon. If this horizon had lost its clay into the subsoil at the rate at which it moved down from horizons 2, 3, and 4, the clay content would have been 9% instead of 6%. Apparently, the rate of loss from horizon 1 was greater than that from horizons 2, 3, and 4, and this loss can be attributed to erosion. The amount of soil lost by erosion is represented by "A" and is equal to about 3% of the whole soil, which is 33.3% of the clay fraction. Data on the loss of phosphate in the eroded clay fraction will be presented later to substantiate this interpretation.

TABLE 1.—*Results obtained on the plats of the Cullars rotation experiment studied.**

Plat No.	Kind of fertilizers used	Total amount of P_2O_5 added in the 26-year period, lbs. per acre	Av. annual crop yields per acre, 1911–1936, inclusive			P_2O_5 removed by harvested crops in 26 years, lbs. per acre†
			Cotton, lbs. seed cotton	Corn, bu.	Oats, bu.	
2	Nitrate of soda, 240 lbs. per acre annually (Kainit and dried blood, 1911–24)	0	723	35.6	35.0	258
3	Superphosphate, 1911–32, none since; nitrate of soda, 240 lbs. per acre, annually (Kainit and dried blood, 1911–24)	1,123	1,239	49.8	48.4	369
4	No fertilizers	0	367	24.6	12.4	132
5	Rock phosphate, 1911–32, none since; nitrate of soda, 240 lbs. per acre, annually (Kainit and dried blood, 1911–24)	3,994	1,195	47.2	50.4	366
8	Superphosphate, 1911 to present; muriate of potash, 50 lbs. per acre, annually (Kainit, cottonseed meal, 1911–24)	715	939	35.4	24.7	234
9	Rock phosphate, 1911–32, superphosphate 1933 to present; muriate of potash, 50 lbs. per acre, annually (Kainit, cottonseed meal, 1911–1924)	2,371	862	36.1	27.3	241
10	Same as plat 9	2,371	647	30.7	23.5	201

*Rotations used: Previous to 1932, cotton—oats, cowpeas, vetch—corn interplanted with cowpeas, vetch. Since 1932, cotton, vetch—corn interplanted with summer legumes—oats, summer legumes.

†These values were obtained by using the following compositions of P_2O_5 in percentage for the harvested crops:
Seed cotton, 0.588. Corn on cob, 0.526. Weight grain oats $\times 2.5$ = weight sheef oats.
Grain oats, 0.755. Corn in husks, 0.465. Weight shelled corn $\times 1.3$ = weight corn in husks. Oat straw, 0.298. Corn husks, 0.252.

The plats have a uniform slope of about 0.8% and thus the area is generally considered to have lost no soil by erosion. Also, the elevation of the permanent plat stakes with respect to the soil indicates that little or no coarse soil material has been lost that would appreciably lower the elevation of the soil. Data in this paper indicate, however, that erosion of the fine soil fractions has been considerable and is very significant in relation to the loss of plant nutrients as exemplified especially by the losses of phosphates.

Horizons 4 and 5 contain 18% clay. Since these two layers contain the same amount of clay, they are taken to represent the transition between the horizons of eluviation and illuvation. This is assuming that the rate of movement into these horizons was equal to the rate of movement out, in which case 18% represents the amount of residual clay in the soil, i.e., the city formed in *situ*. Evidently, the clay has accumulated in horizons 6 and 7 and below the 56-inch depth.

PRESENT PHOSPHATE CONTENT OF THE SURFACE SOILS

The total amount of phosphorus in the soils of the various plats and the solubility of the phosphate at different pH values were determined and the results are shown in Table 2. These data show several facts that are not directly pertinent to the theme of this paper, but are worthy of mention in relationship to the behavior of phosphates.

TABLE 2.—*The total phosphorus content in the surface 8 inches of soil and the amount of phosphate soluble in water at various pH levels in the plats of the cullars rotation experiment on Norfolk loamy sand.*

Plat No.	pH	P_2O_5 soluble at various pH levels, lbs. per acre				Total P_2O_5 by fusion, lbs. per acre 8-inch depth
		pH of soil 1–2, soil-water suspension		pH 3.0, 1–200, 0.002N H_2SO_4	pH 2.0, 1–200, $KHSO_4$	
		Inorganic	Organic			
B*	6.1	0.0	0.3	49	46	312
2	5.4	0.3	0.0	40	50	365
3	5.5	0.9	1.0	50	201	408
4	5.3	0.3	0.0	26	186	269
5	5.4	0.9	0.6	165	372	659
8	5.4	0.0	1.2	130	138	371
9	5.4	1.3	1.6	293	459	812
10	5.4	1.5	1.4	175	459	824

*Soil taken from the hedge fence row at the edge of the plats and represents a soil that has lost no phosphate by erosion or by removal in harvested crops. The phosphate content of this soil is assumed to be similar to that of the soils in the plats before the experiment was started.
*Kainit and dried blood, 1911–1924.

It will be noted that the amount of phosphate entering solution increased generally with the increase in the acidity of the solvent. The amount soluble in water was extremely low, even in the soils that had been heavily phosphated. (See plats 3, 5, 8, 9, and 10 in Table 1). These plats contained the greatest amount of water-soluble organic phosphate. Plats 2 and 4 had received no phosphate fertilizers and contained no water-soluble organic phosphate. The phosphate soluble at pH 3.0 (Truog's method) compared only roughly with the crop yields and with the total phosphates in the soil. The same relation was

true of the phosphates soluble at pH 2.0, except that the amount soluble was usually greater than that at pH 3.0.

The total phosphorus content, obtained by the fusion method on duplicate samples showed a generally low amount of phosphorus in all of the soils. This seems unusual since, for example, plat 2, with no phosphate fertilization, had 365 pounds of P_2O_5 per acre in 8 inches of its surface soil; whereas, plat 5, with 3,994 pounds per acre of P_2O_5 added in rock phosphate over a period of 22 years (none added since 1932) had only 659 pounds of P_2O_5 in the topsoil. If the phosphorus content of soil B in Table 2 is accepted as being similar to that of the plat at the start of the experiment, 312 pounds of P_2O_5, the phosphate in the soil of plat 5 at the beginning of the test, subtracted from the 659 pounds of P_2O_5 leaves 347 pounds of P_2O_5 as the accumulated residue. This leaves 3,647 pounds of P_2O_5 to be accounted for. Subtracting 366 pounds for the P_2O_5 removed from this plat in the harvested crops in the 26-year period (Table 1), 3,281 pounds of P_2O_5 remained to be accounted for as having moved into the subsoil, or as having been lost by erosion.

DISTRIBUTION OF PHOSPHATE IN THE SOIL PROFILE

Since there was only a relatively small amount of total phosphate accumulated in the surface horizons of the phosphated plats, the subsoil horizons of some plats were analyzed to determine if any appreciable amount of the phosphate had moved into the lower horizons. The data of these analyses are given in Table 3. In this table the total phosphate content of the various horizons of the three cropped plats which had received (a) no fertilizer, plat 4; (b) nitrogen only, plat 2; and (c) phosphate plus nitrogen, plat 5, were compared with the total phosphate content of corresponding horizons of the uncropped soil, soil B.

It will be noted that the soil horizons below 8 inches on the phosphated plat, plat 5, had 170 pounds less total P_2O_5 than the same horizons in soil B, which is the check soil in this study representing the composition of the soils in the plats at the start of the experiment. This is evidence that the movement of phosphates into the subsoil was too insignificant to account for any appreciable residual amount of accumulation. From these results the conclusion was made that the phosphate unaccounted for must have been lost in the clays of the muddy waters that have moved off the land in heavy rains. Other evidence to substantiate this conclusion is presented later.

Table 3 shows other facts that are of interest. Plat 2, receiving only a nitrogen fertilizer, produced larger crop yields and gave up more phosphate in its harvested crops than plat 4 which was unfertilized (Table 1). Yet the results (Table 3) show that plat 2 contained 53 pounds more P_2O_5 at the end of 26 years of cropping than it had at the start and that plat 4 had 43 pounds less P_2O_5 in its surface soil than at the start. To find that the larger crop yields had produced the richer surface soil seemed like an unreasonable situation; however, a study of the composition of the subsoils in the two plats shows that the horizons below 8 inches in plat 2 had lost 166 pounds more P_2O_5

than these horizons in plat 4. This indicates that more phosphate had been "pumped" to the surface soil in plat 2 than in plat 4 by the growing plants, thereby causing an enrichment of phosphate in the topsoil on the nitrated plat from the crop residues at the expense of the subsoil. The explanation for this difference is presented in connection with the study of the root systems of corn on these plats.

TABLE 3.—*The total P_2O_5 content in the different horizons of a loamy sand from variously treated plats compared to that in the horizons of the same soil uncropped and unfertilized for a 26-year period with a 3-year rotation of cotton, corn, and oats.*

Depth of soil horizons, inches	Original soil, (soil B), no fertilizers, no erosion, and no crops removed, lbs. total P_2O_5 per acre	Plat 2, 240 lbs. nitrate of soda annually since 1924 and cropped for 26 years*		Plat 4, no fertilizers; cropped for 26 years		Plat 5, 3,994 lbs. of total P_2O_5 in 22 years as rock phosphate, no phosphate last 4 years, plus 240 lbs. nitrate of soda annually since 1924, cropped for 26 years*	
		Lbs. total P_2O_5	Total P_2O_5 content compared with that of Soil B	Lbs. total P_2O_5	Total P_2O_5 content compared with that of soil B	Lbs. total P_2O_5	Total P_2O_5 content compared with that of soil B
Surface soil: 0–8	312	365	+53	269	—43	659	+347
Subsoil:							
8–16	545	346	—199	350	—195	467	—78
16–24	336	418	+82	330	—6	386	+50
24–32	373	308	—65	337	—36	427	+54
32–40	435	266	—169	371	—64	343	—92
40–48	450	266	—184	321	—129	384	—66
48–56	545	462	—83	523	—22	507	—38
Sum of all horizons	2,996	2,431		2,501		3,173	
Loss of total P_2O_5 in horizons below 8 inches			—618		—452		—170

*Kainit and dried blood for the first 14 years.

In comparing the losses of phosphate from the subsoils of plats 2, 4, and 5, it is interesting to note that the loss was 618, 452, and 170 pounds of P_2O_5, respectively. Plat 2 with only a nitrogen fertilizer (nitrate of soda) made surprisingly good yields and contributed 258 pounds of P_2O_5 to the harvested crops. It is obvious that here the crops drew much of this phosphate from the lower horizons. The

residual phosphate enrichment in the surface soil and impoverishment in the subsoil substantiates this fact. Plat 4, with no fertilizers, made the lowest yields and lost only 132 pounds of P_2O_5 in the harvested crops. Undoubtedly, these crops also pulled some phosphate from the subsoil. Plat 5, with phosphate and nitrogen fertilizers, produced larger yields than plats 2 and 4 and lost 366 pounds in its harvested crops. Here the subsoil horizons were only 170 pounds of P_2O_5 short of their original content. Since the behavior on plat 2 indicates that much phosphate has been carried upward by the plant roots of the vigorous plants, the crops on plat 5 with strong plants probably also carried much phosphate upward. Therefore, the 170 pounds loss from the subsoil is likely a value diminished by slight eluviation of clay-fixed phosphate into the subsoil from the phosphated surface soil.

DISTRIBUTION OF PHOSPHATE IN THE SOIL FRACTIONS

In an attempt to learn more about the losses of the residual phosphate, soils from plats 4, 5, and 9 were fractionated into three group sizes of particles and analyzed for the total phosphate content of each. The clay fraction represented material that remained in suspension in the upper 6 inches of a water suspension for 16 hours. The silt fraction was made up of the material that did not settle below the 6-inch depth in 15 minutes but that did settle below that depth in 16 hours. The sand fractions contained the particles that settled below 8 inches in 15 minutes. The fractionation of the silt and sands was repeated several times to separate out the included particles that were not wanted in any of the particular fractions. Some soil material was lost by this washing process; therefore, the sum of the phosphate contents of the three fractions does not exactly equal the total amount found in the whole soil. The soil samples for these fractions were composites from the plats in the middle tier of the experiment only. The total phosphate contents of the different soil fractions are given in Table 4. It is interesting to note that the phosphate content of the clay fractions is much higher than that in the coarser fractions. This fact is most pronounced for plats 5 and 9 which had received phosphate fertilizers. Here, over 50% of the total phosphate in the whole soil is contained in the fine fraction which is only 6% of the total soil. This situation is very significant for it shows how important the clay fraction of a soil really is in its relation to the conservation of phosphates.

The total phosphate content of the surface 8 inches of plat 4, which had received no fertilizers, was only 269 pounds of P_2O_5 per acre. The fractionation data show that this total phosphate content was highest in the clay fraction, but it did not differ greatly in the distribution on the whole soil basis. This fact indicates that the phosphates in this soil are mineral phosphates associated with the internal structures of the soil minerals, whereas the phosphates of the clay fractions of the phosphated plats include also precipitated and surface-absorbed phosphates.

TABLE 4.—*The distribution of P_2O_5 in the various fractions of the surface 8 inches of a Norfolk loamy sand fertilized for 26 years with different fertilizers.*

Kind of soil fractions	Sands	Silt	Clay
Amount of fraction in soil, %	74	20	6
Weight of fraction per acre 8-in. depth, lbs	1,998,000	529,000	173,000
Plat 4, no fertilizers:			
Total P_2O_5 in fractions, by analyses, p.p.m.	52	162	482
Total P_2O_5 in fractions, per acre of soil, lbs.	103	86	74
Distribution of total P_2O_5 in fractions, %	39.2	32.6	28.1
Plat 5, rock phosphate 22 years; no phosphate last 4 years:			
Total $_2O_5$ in fractions, by analyses, p.p.m.	69	224	1976
Total P_2O_5 in fractions, per acre of soil, lbs.	138	118	341
Distribution of total P_2O_5 in fractions, %	23.1	19.7	57.1
Plat 9, rock phosphate 22 years, superphosphate last 4 years:			
Total P_2O_5 in fractions, by analyses, p.p.m.	78	286	1,936
Total P_2O_5 in fractions, per acre of soil, lbs.	156	152	335
Distribution of total P_2O_5 in fractions, %	24.3	23.6	52.0

PHOSPHATE LOST BY EROSION

The various data on the phosphate losses and accumulations are brought together in Table 5 to form a balance sheet for the plats studied. These data show that only about 32% of the P_2O_5 added in the superphosphate and 9% of the P_2O_5 added in the rock phosphate was used by the crops in producing harvested products. Since the accumulation of residual phosphate was extremely small and since only an insignificant amount had moved into the subsoil, as shown in other data of this study, the great loss of phosphate from these plats must be attributed to erosion losses. Thus about 60% of all the P_2O_5 from the superphosphate and 82% of the P_2O_5 from rock phosphate has been washed away from these plats in the 26 years of their duration.

No data are available on the amount of clay material lost by erosion from these plats. The data in Fig. 1 suggests that 3% of the topsoil horizon has been lost by erosion and that this loss was only from the clay fraction. Since the topsoil contained only 6% clay, the loss of 3% of the soil as clay represents about a 33% loss of the clay fraction. Undoubtedly, some of this loss occurred before the beginning of this test. Nevertheless, the data in Table 4 show that if only a slight clay loss had occurred, there would still be a great loss of phosphate, since the phosphate is largely contained in the clay fraction. This seems to be especially true of phosphates fixed in the soil from fertilizers.

To obtain additional data on the phosphate losses from these plats some of the muddy water runoff was collected and analyzed. Three 4-gallon cans were placed on plats 4, 5, and 9, between the rows in such a way that the runoff would be saved. These cans were installed in September 1937 and 2.14 inches of rain fell in small showers before

TABLE 5.—*A balance sheet of the phosphate losses and accumulations in a 26-year period in the top 8 inches of Norfolk loamy sand in plats variously fertilized.*

	Fertilizer treatment						
	Plat 2, nitrogen only since 1924	Plat 3, super-phosphate for 22 years, no phosphate last 4 years, + nitrogen	Plat 4, no fertilizer	Plat 5, rock phosphate for 22 years, no phosphate last 4 years, + nitrogen	Plat 8, superphosphate entire period 26 years + potash	Plat 9, rock phosphate for 22 years, superphosphate last 4 years + potash	Same as plat 9
P_2O_5 in first 8 inches soil at start of test, lbs.	312	312	312	312	312	312	312
P_2O_5 in first 8 inches soil after 26 years cropping, lbs.	365	408	269	659	371	812	824
Gain or loss in the 26 years cropping, lbs.	+53	+86	−43	+347	+59	+500	+512
P_2O_5 added in 26 years, lbs.	0	1,123	0	3,994	715	2,371	2,371
P_2O_5 removed by crops in 26 years, lbs.	258	369	132	366	234	241	201
Percentage of P_2O_5 added used by crops	—	32.8	—	9.1	32.6	10.1	8.5
P_2O_5 supplied from subsoil, assuming no erosion, lbs.	311	?	89	?	?	?	?
P_2O_5 lost by erosion, lbs.	307†	668	363†	3,281	422	1,630	1,658
Percentage of added P_2O_5 lost by erosion	—	60	—	82	59	68	70

*These values obtained from soil B (Table 2) taken from the hedge row at the edge of the plats.

†The data in Table 3 indicate that when the phosphate lost by erosion is included, the amount of P_2O_5 drawn out of the subsoil was 618 lbs. and 452 lbs. for plats 2 and 4, respectively. Accordingly, then, the loss of P_2O_5 by erosion on plats 2 and 4 was the difference between these values and the values given for the P_2O_5 supplied from the subsoil when assuming no erosion, or 307 and 363 pounds, respectively.

any runoff occurred. A 2.92-inch rainfall occurred 21 days later and the cans filled with runoff water containing about 0.3% of suspension.

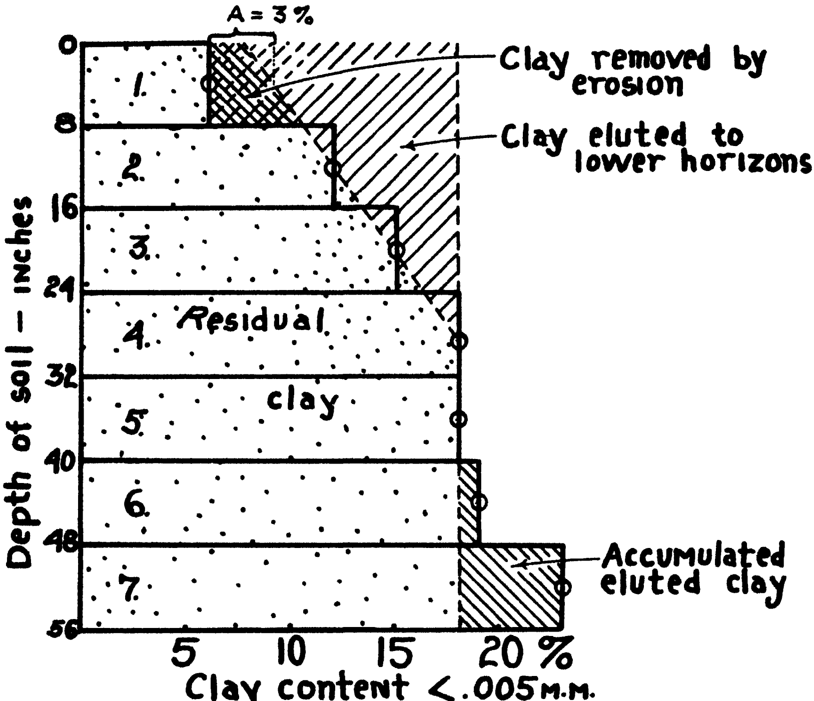

FIG. 1.—Clay content by 8-inch layers of the Norfolk loamy sand from the Cullars rotation experiment and a diagramatic interpretation of the data with regard to the clay that has been lost out of the top soil by erosion, the clay washed out of the upper horizons into the lower subsoil, and the clay accumulated in the lower horizons.

The suspended material in the runoff from plats 4, 5, and 9 contained 660, 687, and 917 p. p. m. of P_2O_5, respectively. These figures are high considering that the data from these plats show that the phosphates have already been lost to the point where the total P_2O_5 content is low. These data also show the manner in which the phosphate losses occur.

The phosphate content in the runoff fraction is not as high on plats 5 and 9 as that of the laboratory separated fraction reported in Table 4. The laboratory samples were taken from the entire 8-inch depth of the surface soil, and thus contained material not exposed to the surface of the land and the dispersing and washing effects of the season's rains; whereas, the runoff samples were composed of material lying on the surface of the land that had been rain washed throughout the summer thereby removing phosphate-bearing clays and causing a lowering of the phosphate content of the top material.

EFFECT OF A NITROGEN FERTILIZER ON THE USE AND CONSERVATION OF PHOSPHATE

The data in Table 6 from plats 2 and 4 where nitrogen and potassium fertilizers and no fertilizers, respectively, were used, show a relationship to the use and conservation of phosphates that helps to explain why an average annual yield of corn and oats of 35 bushels per acre each was possible without the use of a phosphate fertilizer. It has been referred to before that the phosphate content of plat 2 was higher by 53 pounds of P_2O_5 at the end of the 26 years of cropping than at the start of the experiment. The explanation for this seems to be associated with the fact that the nitrogen fertilizer had stimulated the root development to such an extent that more phosphate was used from the subsoil on plat 2 than on plat 4 where the roots were not nearly so well developed.

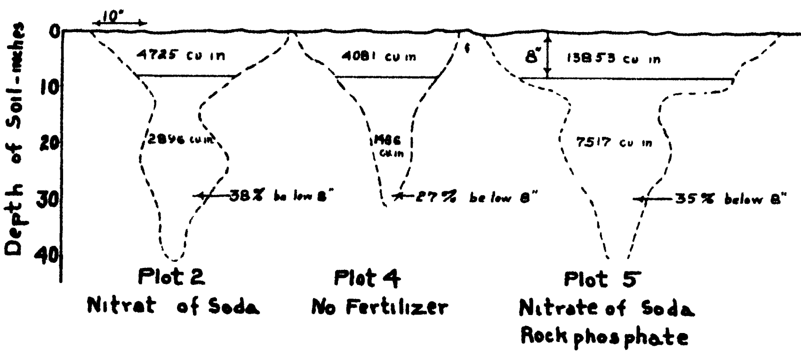

FIG. 2.—Outline of distribution of the root systems of corn on a loamy sand, showing the effect of nitrogen and phosphate fertilizers in stimulating the root growth and the penetration of the roots into the soil below the 8-inch depth.

Fig. 2 shows the outline of the distribution of corn roots on plats 2, 4, and 5. These diagrams were obtained by examining the root distribution from the walls of pits dug beside the stalks. The numbers of small fibrous roots were much more pronounced on plats 2 and 5 than for plat 4. The gross volume for the root spread in the subsoil below the 8-inch horizon was twice as great in the nitrated plat as in the non-fertilized plat. Undoubtedly, the larger phosphate content of the surface soil of plat 2 was caused by the larger plant residues left on the field by the larger crops.

DISCUSSION

The data presented show that the accumulation of phosphate in a clean-cultivated light-textured soil in a humid climate with open winters is not nearly as great as is commonly believed. Since phosphates are not leached as nitrates and potash fertilizers are, the prevailing concept has been that the phosphates are accumulating, especially in fields where erosion is not defacing the land. The data show,

TABLE 6.—*The crop yields and phosphate balance in a loamy sand from a plat receiving no fertilizer and a plat fertilized with nitrogen only.*

Plat No.	2	4
Fertilizer treatment	240 lbs. per acre of nitrate of soda*	No fertilizers
Average annual crop yields for 26 years:		
Cotton, lbs. seed cotton per acre	723	367
Corn, bu. per acre	35.6	24.6
Oats, bu. per acre	35.0	12.4
P_2O_5 in acre 8-inch depth:		
At start, lbs	312	312
At end, lbs	365	269
P_2O_5 gained or lost in 26 years, lbs	+53	—43
P_2O_5 removed by crops in 26 years, lbs	258	132
P_2O_5 brought out of subsoil in 26 years, lbs	305	89
Soil-root volume, 0–8 inches, cu. in	4,725	4,081
Soil-root volume below 8 inches, cu. in	2,896	1,496

*Kainit and dried blood for the first 14 years.

however, that the phosphate losses are very large even if the land shows no apparent mass or accelerated erosion, because whatever the amount of the muddy water that runs off the land, it carries off heavy loads of phosphates that are associated with the clay fraction of the soil. When it is considered that phosphate is usually the highest percentage ingredient in most of the common mixed fertilizers and only 9 to 32% of this ingredient is used by the crops in making harvestable products, the economic loss becomes very great when the unused portion is permitted to be washed away. If the clay runoff were stopped, the phosphates would accumulate and eventually the stress for phosphate would be relieved. The accumulation of phosphate is important even if the phosphates are fixed into relatively insoluble forms. A solubility of 0.01% would yield 10 pounds of available phosphate from a residue of 1,000 pounds of P_2O_5, which might be enough for the plants; yet, the same solubility for a lower residual amount of phosphate would be inadequate. This illustration is borne out in a pasture fertilization experiment in the Black Belt of Alabama where 200 pounds of 16% superphosphate per acre in an annual application is sufficient for good plant growth after several years, but was not sufficient at the start. On these soils approximately a 400-pound rate of this fertilizer is required for the cultivated crops where erosion losses are greater. On a sandy loam soil (Hartsells) at the Sand Mountain Substation an experiment on the residual effect of phosphate showed that 90 pounds of P_2O_5, applied annually for a period of 5 years, did not result in a phosphate carry-over sufficient to maintain the cotton yields for 2 years. In view of the present data, this suggests a great erosion loss as well as a loss by fixation.

This paper has dealt with phosphate losses as only one factor in the maintenance of productive soils. The significance of these results reach

beyond this one factor for in the conservation of phosphates other important elements as potassium, calcium, and magnesium, and minor elements are also conserved. The benefit of a protective winter cover crop with roots drawing minerals from the subsoil to become incorporated into the surface soil from the plant residue cannot be overemphasized. Furthermore, if the soil is to build up its storage of plant nutrients to be revolved through the plant back to the soil, and in the bodies of micro-organisms, it is of the greatest importance that the loss of the clay fractions of the soil in muddy waters be prevented. It is also important to recognize that terraces as commonly constructed in the Southeast cannot alone adequately conserve the clay fractions that are so essential in maintaining soil fertility.

One more point about the conservation of the clay fractions to save the phosphate should be mentioned. The phosphate deposits are limited and can be exhausted (10); therefore, it is well to recognize all the factors that contribute to the efficient use of phosphate as fertilizers.

SUMMARY

A study was made of the residual phosphate situation in a nearly level, light-textured soil of Alabama that had been used for a 26-year period in an experiment involving a 3-year rotation of cotton, corn, and oats with various legumes and with different phosphate fertilizer treatments. The soil has been considered to be uneroded or not seriously eroded, and it has been assumed that the unused phosphates were accumulating in the soil as fixed phosphates. The data presented reveal that some of these assumptions are not correct. The principal facts are summarized as follows:

1. Where superphosphate was used for the 26-year period, 32% of the phosphate was used by the plants in making harvested products, 8% was still present as a residue, and 60% had been carried away with the clay fractions lost by erosion.

2. Where rock phosphate was used, only 9% of the total phosphate added was used by the plants and 82% was lost by erosion, the amount remaining as a residue being 9%.

3. The surface soil contained only 6% of clay, yet, in this fraction was held over 50% of the total phosphate in the soil.

4. The amount of phosphate that had moved downward in the profile was too insignificant to measure accurately; apparently, a small amount had moved down with the eluted clay.

5. The total amount of phosphate taken out of the subsoil below the 8-inch depth in 26 years by the crops on a plat receiving only a nitrogen fertilizer was 618 pounds P_2O_5 per acre. Of this amount 258 pounds were removed from the field in harvested crops, 53 pounds accumulated in the surface 8 inches, and 313 pounds, or 60% lost by erosion.

6. A nitrogen fertilizer had maintained a 35-bushel corn and oat yield per acre for a 12-year period[4] without the use of phosphate fertilizers and had at the same time caused a slight increase in the total

[4]This is a 26-year period without phosphate fertilizers for kainit was used with the nitrogen the first 14 years.

phosphate content of the surface 8 inches of soil by drawing phosphate from the subsoil horizons. A plat with no fertilizers produced only 24 and 12 bushels per acre yields for corn and oats, respectively, and had depleted the surface soil by 43 pounds of P_2O_5 per acre. The difference in the yields and phosphate contents of the soil is accounted for by the increased root growth in the subsoil of the nitrated soil and the greater upward movement of the phosphate from the subsoil in the more vigorous plants.

7. The data are discussed in relation to the importance of saving the clay fraction in soil conservation practices.

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THE CYTOLOGY AND HISTOLOGY OF THE ROOT NODULES OF SOME LEGUMINOSAE[1]

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VARIOUS phases of nodule formation on leguminous plants have already been studied by investigators.[3] This paper deals with the comparative cytological and histological development of nodules of the following leguminous plants: Soybean (*Soja max* Pieper), cowpea (*Vigna sinensis* Endl.), sweet clover (*Melilotus alba* Desr.), alfalfa (*Medicago sativa* L.), vetch (*Vicia villosa* Roth.), and peanut (*Arachis hypogaea*).

MATERIALS AND METHODS

The materials used in this investigation were obtained by growing plants in the greenhouse, in the laboratory under artificial light, and also in the field. In the greenhouse and laboratory, the plants were grown in (a) washed sand, (b) Knop's water culture in bottles, and (c) a soil consisting of one-third sand and two-thirds loam.

For early infection stages, the seeds were germinated in petri dishes between filter paper, and inoculations from agar slants were made by applying the bacteria directly to the root hairs. The bacteria used for inoculation were obtained as follows: (a) By grinding up mature nodules and making a water suspension, (b) by using soil which already contained nodule-forming bacteria, (c) by using commercial preparations of bacteria, and (d) by isolating and growing on agar slants.

The bacteria were either applied directly to the seed before planting or to the medium in which the plants were to be grown. When water cultures were used, the roots were suspended in the solution. The stems were wrapped with cotton and held erect by split stoppers. The bottles were wrapped and solution added when needed. Small crucibles with holes in the bottoms were filled with sand and partially embedded in flower pots filled with loam soil. Seeds were then planted in the crucibles. Nodules formed in the crucible, while the roots penetrated the openings in the bottoms.

An abundance of material for study was easily obtained by the above methods. Materials for study were selected at various times of the day in order to increase the possibility of obtaining cells undergoing mitosis. The killing and fixing solutions used were as follows: Flemming's weak and Bouins and chromoacetic for the younger tissue. A. F. A. solution was used for the older tissues. Other killing and fixing solutions were tried but proved less satisfactory. The paraffin method of infiltration and embedding was used for the younger tissue, but for the older and more lignified tissue, the celloidin method was employed.

Free-hand sections of fresh material were cut to make microchemical tests for starch, protein, cellulose, lignin, and gums. The embedded material was cut 8 to 20 microns in thickness. The age of the material after inoculation ranged from 12

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[3]For a more complete historical review see Fred, E. B., Baldwin, I. L., and McCoy, Elizabeth F. Root nodules and leguminous plants. Univ. Wis. Studies in Sci., No. 5, 1932.

hours to 11 weeks. The stains used were Delafield's haematoxylin, safranin, carbol, fuchsin with Bismark brown, and Grams iodine. The best general combination of stains used was Mayer's haeum-alum and aqueous safranin. The procedure with this combination is simple and the staining is rapid as compared with some of the other stains used.

NODULE DEVELOPMENT IN SOYBEAN

INFECTION OF HOST TISSUE

The bacteria causing nodule formation on soybeans usually enter the host plant through the root hairs (Figs. 1, 3, 7, and 8). When the bacteria come in contact with the root hairs, a characteristic curving usually occurs (Figs. 1, 3, and 7). However, in the soybean and cowpea, infection may take place without the formation of such a curvature (Fig. 1, a). Root hairs were also found in which infection apparently took place simultaneously on opposite sides of the root hair (Fig. 1, a). From further observations it was concluded that this curvature usually takes place when infection occurs during the elongation period of the root hairs. However, if infection occurs in root hairs after elongation has ceased, this curvature will not always be exhibited.

It is apparently also possible for bacteria to enter the host plant through regular epidermal cells (Fig. 2). This was found to occur most frequently when seedlings were grown in a medium in which they obtained an abundance of moisture and produced fewer root hairs. Bacteria may also enter through breaks in the epidermis. Very little difficulty was encountered in getting infection to take place in the soybean.

Thornton (6)[4] found that infection coincides with the opening of the first true leaves. No such correlation was found in the soybean. It was noted that many seedlings would die or become stunted just at the stage when they were breaking through the soil before unfolding their cotyledons. This was especially found to occur when a medium was used which was highly infested with nodule-forming bacteria, such as equal parts of sand, loam, and commercial "Nitragin". Those seedlings which survived always showed a very heavy inoculation and a poorly developed root system. From all observations made, it was concluded that the stunting or death was a result of excessive infection. Thornton (7) concluded that nodule-forming bacteria are sometimes parasitic.

The bacteria begin the formation of an infection or zoogloeal strand immediately after gaining entrance to the host cell. This strand resembles a non-septate fungus hypha (Figs. 1, 2, 3, 7, and 8), and can readily be distinguished from the cytoplasm of the cell. The infection strand, in which the bacteria are embedded, has a gum-like consistency. Buchanan (1) found that nodule-forming bacteria produced large quantities of gum. It requires approximately two days from the time that the bacteria come in contact with the tip of the root hair until they have reached the inner wall of the epidermal cell, a distance

[4]Figures in parenthesis refer to "Literature Cited", p. 389.

of 70 to 80 microns. The number of infection strands invading the root hairs of the soybean was found to vary from one to three (Fig. 7, a).

The bacterial strand may branch or remain in a single strand while invading the root hair and basal portion of the epidermal cell (Figs. 1 and 8, a), but when the strands penetrate the cortex, branching takes place almost invariably. The branches of the infection strand ramify the cortical parenchyma (Figs. 1, 2, 3, and 8). It is from these cortical parenchyma cells that the nodule develops in the soybean. The strands in their migration often come directly in contact with the nucleus. The cells that are being invaded and those immediately surrounding them have a rather dense cytoplasm and prominent nucleus. Because of their active division, they are much smaller than the surrounding cortical parenchyma cells (Figs. 2, 7, and 9). Infection may take place at various stages of root growth. Early infection stages were found on roots which already had nodules large enough to be easily detected (Fig. 9, b). Frequently infections were noted in which the bacteria had entered through the root hair, migrated to the inner wall of the epidermal cell, but failed to penetrate deeper.

The distance which the bacteria penetrate the cortical parenchyma of the root is important in determining the exact point of the origin of the nodule. In the soybean, which has a rather thick cortical parenchyma, it was found that the infection strand penetrated only from three to five layers of the cortical parenchyma cells (Figs. 1, 7, and 9). In the radicle, the strand ordinarily penetrates to a distance about half-way between the epidermis and endodermis. In the lateral roots of the soybean, there is less cortical parenchyma and the bacteria may even penetrate the cortex to the endodermis. In no instance was it found that the bacteria had penetrated the endodermal cells. In the cortex, the bacteria appear to move towards one of the protoxylem points. However, the bacteria never reach the protoxylem since they do not pass through the endodermis or pericycle. When the bacteria have penetrated several layers of cortical parenchyma, the formation of a vascular system is initiated, forming a direct connection between one of the protoxylem points and the infected area (Figs. 9, c, 10, b, and 11, b). It appears that there is considerable transfer of material between the protoxylem and the infected area. The development of this vascular system will be described in detail later.

The infection strands within the cortex increase considerably in size. In the strands, enlargements are formed that break and liberate the bactera (Fig. 2, a). The division of cells also breaks the infection strands, liberating the bacteria into the surrounding cytoplasm. The bacteria then multiply rapidly and fill the cells. This increase in bacterial number within the cells and products of bacterial secretion apparently cause an increased internal pressure which brings about an enlargement of the cell. Because of the frequent cell divisions of the bacteroidal cells in the soybean, the infection strand is broken up into small particles and its identity completely lost (Figs. 12, a and 13, a).

Formation of the nodule begins as soon as the bacteria have invaded the sub-epidermal layer. In the soybean, the nodules originate in the third to fifth layers of cortical parenchyma cells (Fig. 9). The

epidermal cells are sloughed off, the second layer forms the epidermis of the nodule, the third layer forms the cortex of the nodule, while the fourth and fifth layers give rise to the bacteroidal tissue. During the early period of infection when the bacteria are moving toward the base of the epidermal cell, the cell enlarges greatly (Figs. 2, b, 7, a, 8, b, and 10, a). The layers below do not show such enlargement, but they are at this time beginning a very active period of cell division. The sub-epidermal cells containing bacteria are surrounded by uninfected cells during this period of active cell division. No infected cells are exposed, but they are completely surrounded by uninfected cells which are continuous with the epidermis and cortex of the root. The cortical cells containing bacteria continue to divide and enlarge, pushing outward against the epidermal layer that surrounds the infected area (Fig. 10). As the infected area increases, the cells in the outer layer also divide and expand, permitting growth to take place. In this manner, the nodule continues to grow. The young nodule does not break through the outer layers of cortical parenchyma, and it in no way resembles a lateral root in origin or development.

The soybean nodules can be detected without the aid of a hand lens within nine days after the inoculated seed has germinated (Fig. 9). At this stage, the infection strands in the soybean have almost completely lost their identity. Uninfected cells are no longer invaded by the bacteria, but the bacteroidal tissue is increased by the division of the infected cells. In the early infection stages, it was difficult to obtain material showing many mitotic figures (Fig. 2). Apparently cell division in these early stages takes place very rapidly. Attempts were made to study periodicity of the nodules The greatest number of dividing cells were found in material selected at 10:30 a. m. on bright days (Figs. 12 and 13). Mitotic figures were also found in abundance in material selected at 1:00 p. m. and 4:30 p. m. Cell division was less frequent in materials selected at other hours. The greatest number of mitotic figures was found on days with a maximum of sunlight. The number of times an infected cell can divide could not be determined, as a large number of bacteroidal cells are formed from a comparatively small number of cells infected by the bacterial strands. The activity of the cell at first seems not to be affected by the presence of bacteria within the cell. After the cell has become well filled with bacteria, mitosis ceases. The cell, however, continues to increase in size and is often much elongated (Fig. 15). As the nodule matures, the nucleus becomes less prominent, gradually shrinks, becomes very irregular, and finally only fragments of it remain.

Scattered among the bacteroidal cells are uninfected parenchyma cells. Mitotic figures were not found in these uninfected cells after the nodule had begun to enlarge (Figs. 14, b and 15, a).

DEVELOPMENT OF CONDUCTIVE TISSUE

An elaborate conductive system is developed between the nodule and the xylem and phloem of the root. This conductive system becomes evident early in the nodule development. The first indication of conductive tissue formation becomes apparent when the bacteria have penetrated the first two layers of cortical parenchyma (Figs. 7,

b, 9, c, and 10, b). The first visible sign of conductive tissue formation is a division of cortical parenchyma cells between the protoxylem point and the infected area. These cortical parenchyma cells divide in such a manner that the new walls formed are almost invariably laid down parallel to the radius of the root (Figs. 9 and 10). These cells form the procambium strands which are later converted into scalariform vessels, and other conductive tissues (Figs. 17 and 18). The first conductive tissue formed is always connecting the infected area with one of the protoxylem points. Frequently conductive tissue is formed connecting the infected area with two protoxylem points (Fig. 11, b). During formation of the procambial strands, the cytoplasm is absorbed and the nucleus, much elongated, is often found lying next to one of the walls. Gradually the nucleus and remaining cell contents are also absorbed. The walls of the cells become lignified and develop into pitted tracheids and scalariform vessels (Figs. 5 and 17).

The cells surrounding the xylem are composed of parenchyma cells having a rather conspicuous nucleus and dense cytoplasm. These cells are filled with stored food, mainly starch. As the nodule continues growth, the cells surrounding the xylem continue to divide (Figs. 5 and 13, b) and increase the diameter of the vascular bundle which differentiates into xylem elements. At the region of connection between the vascular bundle of the nodule and xylem of the root, the new xylem of the bundle is in contact with the new xylem of the root. The vascular bundle becomes cone-shaped at the region where it comes in contact with the xylem of the root. The vascular bundle branches and completely surrounds the bacteroidal area. The number of branches formed is not always constant, and the bundles do not come in contact with the bacteroidal tissue. Several layers of cortical parenchyma are always found between the bundles and bacteroidal cells (Fig. 16, c). The food, water, and other products are transported through the bundle but must diffuse through several layers of parenchyma cells before reaching the bacteria. The branches of the vascular system are also formed from procambium strands in the cortical parenchyma of the nodule (Figs. 4 and 16). More xylem and phloem cells are added to the bundles by division of cells immediately surrounding the bundles (Figs. 4, 5, and 16, b). Toward the apex of the nodule, xylem elements may not have formed as yet. The bundles have no definite arrangement except that the xylem is surrounded by parenchyma cells that are of a phloem-like nature (Figs. 5, 16, and 19). These parenchyma cells retain their meristematic power and add xylem to the bundle as the nodule increases in size (Figs. 5 and 16, a). In cross section, the branches of the vascular system often appear eccentric. In the mature nodule of the soybean, the branches of the bundle unite at the apex of the nodule. The vascular system continues to function after the nodule is fully mature and until the nodule disintegrates.

MERISTEMATIC ACTIVITY

Soybean nodules are spherical and from 3 to 6 mm in diameter. The shape of the nodule is determined by the various meristematic regions. The bacteroidal cells divide until the nodule is 12 to 18 days

EXPLANATION OF ILLUSTRATIONS

The drawings were made with an Abbe camera lucida and the photomicrographs with a microscope equipped with apochromatic objectives and compensating ocular.

FIG. 1.—Bacterial strands entering through root hairs and ramifying cortical parenchyma. ×385. (a) Two infections taking place simultaneously in a single root hair. (b) Branching of bacterial strand.

FIG. 2.—Infection through a regular epidermal cell and mitotic figure in parenchyma. ×385. (a) Break in bacterial strand liberating bacteria into cytoplasm. (b) Enlarged epidermal cell.

FIG. 3.—Two infection strands in root hair penetrating cortex. ×385.

FIG. 4.—Early stage in the development of a branch of the vascular system of a soybean nodule. ×350.

FIG. 5.—Later stage in the development of a branch of a vascular bundle of the soybean nodule. Note thick-walled xylem cells surrounded by phloem-like tissue. ×350.

FIG. 6.—Apical meristem as it occurs in alfalfa, vetch, and sweet clover nodules. ×350. (a) Apical meristem. (b) Infection strand invading newly formed cells. (c) Vascular bundle.

FIG. 7.—Three bacterial strands entering through a root hair and penetrating the cortex. ×300.

FIG. 8.—Bacteria entering the cortex. ×900. (a) Infection strand branching. (b) Epidermal cell.

FIG. 9.—Ten-day-old nodule and vascular system showing early stage of formation. ×75. (a) Root hair through which infection occurred. (b) An infection that failed to develop a nodule. (c) Formation of vascular system.

FIG. 10—A 12-day-old nodule showing the formation of the vascular system and enlargement of the infected area. ×50. (a) Enlarged cell showing portion of root hair where infection occurred. (b) Cortical parenchyma giving rise to conductive tissue.

FIG. 11.—A 15-day-old nodule forming vascular connections with two protoxylem points. ×50. (a) Bacteroidal tissue. (b) Vascular bundle.

FIG. 12.—Portion of bacteroidal area showing cell division in a 12- to 15-day-old soybean nodule. ×600. (a) Infected cells with mitotic figures. (b) Cambial cells surrounding bacteroidal tissue.

FIG. 13.—Bacteroidal tissue of 15- to 18-day-old soybean nodule with mitotic figures. ×600. (a) Infected cells with mitotic figures. (b) Cross section of vascular bundle with mitotic figures.

FIG. 14.—Bacteroidal cells of soybean nodules with vacuoles. The nodule is still in enlargement stage but no mitotic figure. ×600. (a) Vacuoles. (b) Uninfected cell.

FIG. 15.—Bacteroidal cells of a mature nodule. Note how cells have elongated and vacuoles have decreased. ×600. (a) Uninfected cell.

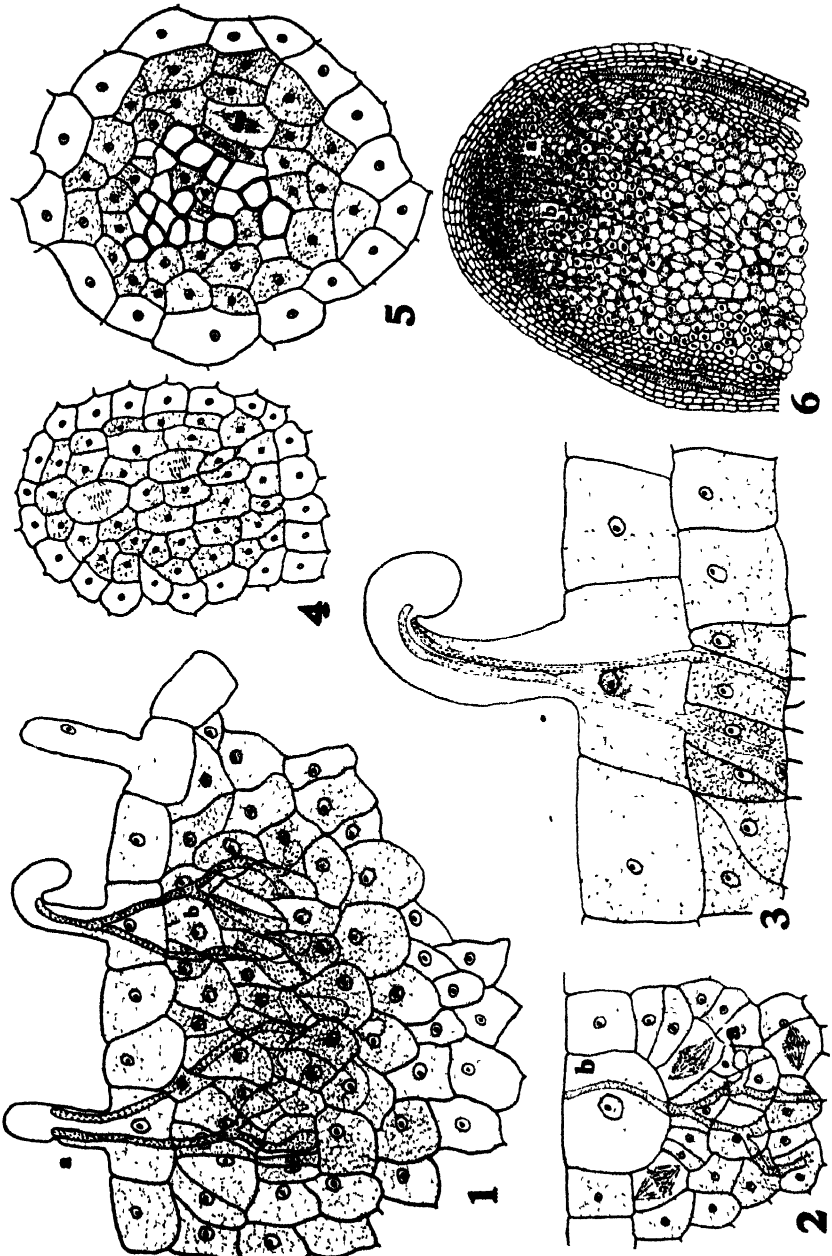
FIG. 16.—Nodule showing the development of the vascular system around the infected area. ×600. (a) Longitudinal section of bundle with mitotic figure. (b) Cambial layer surrounding bacteroidal tissue. (c) Cortical parenchyma. (d) Bacteroidal tissue.

FIG. 17.—Formation of vascular bundle from procambial strand; longitudinal section of soybean nodule. ×400.

FIG. 18.—Region of connection of vascular bundle to the central cylinder of the soybean. ×115. (a) Protoxylem point. (b) Secondary xylem. (c) Cambial layer of root.

FIG. 19.—Cross section of a branch of a vascular bundle surrounding the infected area of soybean nodule. ×330. (a) Xylem. (b) Phloem-like parenchyma. (c) Cortical parenchyma.

FIG. 20.—A section of a soybean nodule showing starch grains and vascular bundle. ×100. (a) Bacteroidal cells. (b) Vascular bundle. (c) Starch grains.



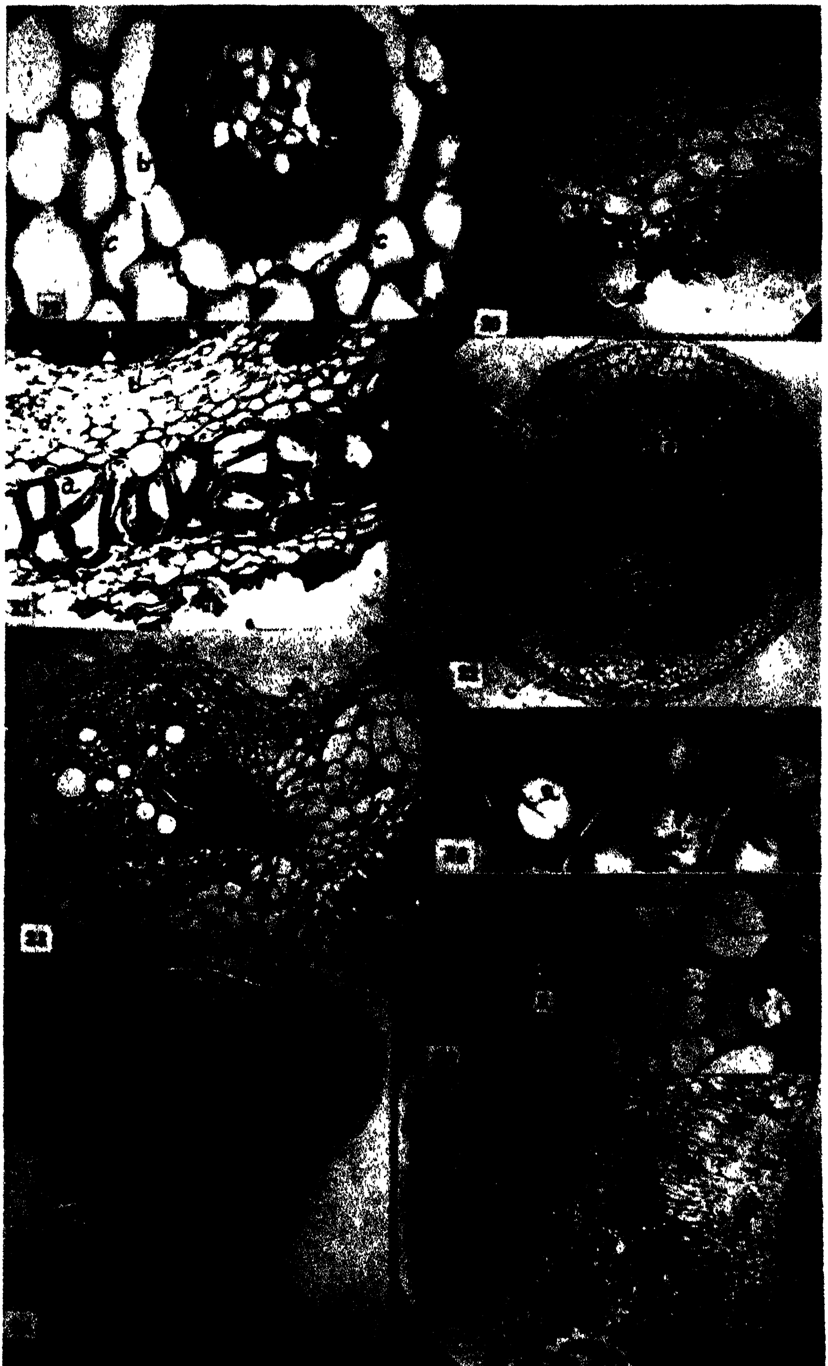


FIG. 21.—A mature soybean nodule with thick-walled cells in the parenchyma surrounding the bacteroidal tissue. ×600. (a) Sclerenchyma. (b) Bacteroidal cells. (c) Vascular bundle. (d) Cortical parenchyma.

FIG. 22.—Cross section of nodule and root of the cowpea. ×39. (a) Vascular bundles. (b) Cambial layer. (c) Cork layer. (d) Cross section of root. (e) Uninfected cells.

FIG. 23.—Portion of cowpea nodule showing cortical layer of root continuous with nodule. ×94. (a) Vascular bundle. (b) Cambial layer. (c) Cork layer. (d) Protoxylem point.

FIG. 24.—Sweet clover nodule longitudinal section. ×39. (a) Apical meristem. (b) Vascular bundle. (c) Old bacteroidal cells. (d) Newly + infected cells. (e) Root.

FIG. 25.—Bacteroidal cells of alfalfa nodule. ×660. (a) Remains of infection strand across vacuole. (b) Disintegrating nucleus. (c) Starch in uninfected cells.

FIG. 26.—Cowpea nodule showing fungus entering epidermal layer and passing through the cortex and reaching the bacteroidal cells. ×440. (a) Fungus hyphae. (b) Bacteroidal cells. (c) Cortical parenchyma.

FIG. 27.—Cowpea nodule showing disintegration caused by fungi while nodule is still in a stage of growth. ×220. (a) Fungus infection. (b) Growing region.

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old (Figs. 12 and 13). Mitosis occurs in all planes, and when cell division ceases, the infected cells increase to several times their normal size. A cambium-like layer surrounds the bacteroidal cells and permits their expansion (Fig. 12, b). Parenchyma cells that are meristematic surround the xylem in the bundles (Figs. 5 and 1, b). These two meristematic regions increase the tissue surrounding the bacteroidal area. Growth takes place acropetally until the vascular bundles are united at the apex. This acropetal growth accounts for the marked elongation of many bacteroidal cells (Fig. 15). A cork cambium originated in the outer layers of the cortical parenchyma. The cork cambium and cork layer are continuous with those of the root (Figs. 21, 22, and 23).

SCLERENCHYMA IN SOYBEAN NODULES

A conspicuous layer of sclerenchyma cells develops in the cortical parenchyma as the nodule matures (Fig. 21, a). This layer completely surrounds the vascular and bacteroidal tissue in the nodule and is connected to the libriform fibers in the root. The thickened walls are a result of successive layers of cellulose deposited on the primary walls of parenchyma cells. When thickening of the cell wall begins, the walls give a microchemical test for cellulose; however, they soon become lignified. The nucleus remains in the lumen of the cell after lignification. The development of this layer of sclerenchyma terminates the growth of the nodule. Such layers are not found in other legume nodules investigated. Embedded simple pits are very prominent in these thick-walled cells.

VACUOLES IN BACTEROIDAL TISSUE

Vacuoles occur rather abundantly in the older bacteroidal cells (Figs. 14, 15, and 20). Vacuole formation appears to be the first indication of cessation of cell division. In the area showing vacuoles, mitotic figures were not prevalent. In the mature nodules, vacuoles were not found in such abundance. Apparently they disappear as the

nodule reaches maturity. Vacuoles may form singly or in clusters around the nucleus (Fig. 14). A vacuole may enlarge to such an extent that it occupies most of the volume of the cell, crowding the nucleus, the remainder of the cytoplasm, and bacteria against the inner cell walls. In the mature nodule apparently the vacuoles disappear, permitting the bacteria and cytoplasm again to occupy the entire volume of the cell.

STARCH GRAINS IN NODULES

Fig. 20 shows a portion of a soybean nodule with starch grains stained with IKI. The starch grains are found most abundantly in normal cells scattered throughout the bacteroidal tissue, in the vascular bundle and in cortical parenchyma near the bacteroidal tissue. Many of the starch grains appear to be large tetrads. The starch did not always give the blue color with IKI, but a yellow and brown instead. According to Palladin (3), this is an indication of starch hydrolysis. In the young nodule, starch was not as abundant. When disintegration of the nodule begins, the starch grains again disappear.

NODULE DEVELOPMENT IN VETCH

Nodules on vetch are much smaller than soybean nodules and are club-shaped, frequently branched. The mode of infection in vetch is similar to that of the soybean. The infection strand may penetrate the cortex until it reaches the endodermis, since there is much less cortical parenchyma in roots of vetch than in soybean roots. However, vetch nodules arise in the cortex and not in the endodermis or pericycle. The origin of the vetch nodule is like that of the soybean.

DEVELOPMENT OF BACTEROIDAL TISSUE

Cell division in the bacteroidal tissue of vetch is not as obvious as in the soybean, and the infection strand does not lose its identity during nodule development. The bacteroidal tissue is increased mainly by the continual invasion of new tissue laid down by an apical meristem instead of by the division of infected cells (Fig. 6, a). The infection strands run parallel, spreading toward the apex. This accounts for the club-shaped nodule. If, during growth, some of the cambial cells in the periphery function at a different rate or cease dividing entirely, the result will be branching of the nodule. There is no other definite cambial region except at the apex.

VACUOLES IN VETCH NODULES

Vacuoles appear much earlier in the bacteroidal cells of vetch than of soybeans. They enlarge much more rapidly and frequently occupy half the volume of the cell. The bacteria and cytoplasm are crowded towards the walls of the cell and forced to occupy a much smaller volume, as illustrated in Figs. 24 and 25. From observations made, it appears that the vacuoles disintegrate after reaching a certain size. Nuclear behavior of infected cells appears to be rather inconspicuous. The nucleus becomes somewhat flattened against the vacuole and

gradually breaks up into fragments (see Fig. 25, b). According to Terby (5), the nucleolus is the first to disappear.

CONDUCTIVE TISSUE FORMATION AND CAMBIAL ACTIVITY

A vascular system is formed connecting the xylem and phloem with the nodule soon after infection has occurred. The vascular bundles develop from procambium strands laid down by the peripheral meristem (Fig. 6, c). The addition of the new xylem from a cambial cell is not as obvious as in the soybean nodule. Peirce (4) suggested that growth of the nodule is limited by the vascular system.

The branching of the nodule and growth from one meristematic region prevents the vascular bundle branches from uniting at the apex. The vascular bundles are separated from the bacteroidal cells by cortical parenchyma. Cambium-like cells, surrounding either the bacteroidal tissue or vascular bundles, are not obvious. Growth of the nodule continues through most of the growing season. The entire nodule is covered with a corky layer, continuous with the root, as shown in Fig. 24 of the sweet clover nodule.

UNINFECTED PARENCHYMA

Uninfected parenchyma cells were noted in the bacteroidal area. These uninfected cells do not enlarge markedly, and cell division was not apparent. These cells were derived from the apical meristem and infection strands failed to penetrate them. Considerable starch was stored in these cells, as well as in cortical parenchyma cells surrounding the bacteroidal area.

NODULE DEVELOPMENT IN COWPEA

Nodules of the cowpea are spherical and develop to about the size of a small pea (Fig. 22). Although their shape, origin, and development are almost identical with that of the soybean, they are not caused by the same organism. Cowpea seeds are easily inoculated and small nodules appear on the seedling in about 10 days. The cowpea nodules, like soybean nodules, arise in the cortical parenchyma. The infection strand is broken up by the dividing cells. The bacterial area increases by cell division, followed by a marked enlargement as in the soybean (Fig. 13). The bacteroidal cells in the cowpea increase to several times their normal size. Vacuoles are formed that can be seen very distinctly and behave like those in the soybean (Fig. 22). Starch grains were found in abundance in the uninfected cells in the bacteroidal area, in the cortical parenchyma, and in the phloem-like cells surrounding the xylem. Apparently the uninfected cells in the bacteroidal tissue divide, as a large number of such cells was prevalent in the bacteroidal area.

CONDUCTIVE TISSUE DEVELOPMENT AND CAMBIAL REGIONS

Vascular bundles are formed from procambium strands and completely surround the infected area (Figs. 22 and 23, a). Cells surrounding the vascular bundles retain their meristematic activity and add

new tissue to the bundle, as shown in Fig. 12 of the soybean. In the mature nodule, the vascular bundles unite at the apex. A cambium-like layer can be noted surrounding the infected area (Figs. 22, b and 23, b). A cork cambium is formed, and considerable corky tissue is laid down on the outside of the cortical parenchyma (Figs. 22 and 23, c). This cork cambium is continuous with the cork cambium of the root.

NODULE DEVELOPMENT IN ALFALFA AND SWEET CLOVER

FORM, ORIGIN, AND DEVELOPMENT

The root nodules of alfalfa and sweet clover are club-shaped and often branched (Fig. 24). In origin and development, they are almost identical with the vetch nodule. However, the nodules of alfalfa and sweet clover are usually in much larger clusters. In the bacteroidal tissue of alfalfa and sweet clover, cell division is not as obvious as in the soybean and cowpea. Infection strands can be noted in the enlarged bacteroidal cells (Fig. 25, a). Bacteria were not found in these old strands and apparently had escaped from the strand into the cytoplasm. The formation of vascular bundles around the cortex is the same as that of the vetch. Vacuoles appear somewhat more conspicuous than in the other nodules studied. Starch grains were found in abundance in the different regions of the nodules the same as in other nodules studied (Fig. 25, c).

NODULE DEVELOPMENT IN PEANUT

The peanut forms nodules which are similar in origin, development, and structure to those of the soybean and cowpea. The peanut produces an abundance of nodules when inoculated. In shape, the nodules are spherical but do not grow as large as the soybean and cowpea nodules.

FUNGI WITHIN THE NODULES

Filamentous fungi were found within the nodule of the soybean and cowpea. The fungus hyphae were septate and much larger than the infection strands. The hyphae penetrated the nodule, passing through the corky layer, cork cambium, cortical parenchyma, and reached the bacteroidal area (Fig. 26, a). From all indications these fungi are able to penetrate the nodule anywhere and do not depend upon a break in the epidermal layer. The cells through which the hyphae passed did not show any signs of necrosis until the fungi had reached the bateroidal area. When the bacteroidal area is invaded, disintegration of the nodule apparently begins, although the nodule may continue its growth after it has been invaded by the fungi. Fig. 27 shows a nodule in which growth was taking place in one portion (a), while disintegration was occurring in other regions.

Nodules of various sizes were selected, sterilized with 5% formaldehyde, and kept at room temperature. In 5 days, 20%, of the nodules were completely covered with a fungus mycelium that was exuding from the interior of the nodules. The fungus was of a light gray color

and was septate. Fruiting, however, was not obtained, thus making it impossible for identification. McCoy (2) reports finding fungi but that they were saprophytic.

SUMMARY

1. The nodule-forming bacteria were found to enter the host plant by the aid of an infection strand, usually through the root hairs, causing a characteristic curvature of the root hair as reported by other investigators; however, this curvature was not exhibited by all infected root hairs.

2. The bacteria-forming nodules may also enter the host through ordinary epidermal cells. Not all of the bacteria entering the host form nodules. The time at which infection can occur in the soybean is variable.

3. Large numbers of nodule-forming bacteria may retard the growth of a young seedling. The bacteria apparently are parasitic during early stages of nodule development and thereby interfere with the normal functioning of the root hairs.

4. The endodermis is not penetrated by nodule-forming bacteria in the leguminous plants studied and the nodules arise only in the cortical parenchyma and not in the pericycle, as do lateral roots as reported by some authors. Nodules formed on roots, which have only a few layers of cortical parenchyma cells, may appear to arise in the endodermis or pericycle.

5. The bacteroidal tissue in the soybean and cowpea nodules increases by division of infected cells. The infection strand is broken up by cell division and loses its identity. The bacteroidal tissue of alfalfa, sweet clover and vetch is mainly increased by the infection of new tissue which is continuously laid down by a meristem. The infection strand remains unbroken in the bacteroidal cells. Variation in the rate of cell division in the meristem will result in a branched nodule.

6. The older bacteroidal cells in the soybean and cowpea nodule lose their ability to divide and the nucleus disintegrates. Vacuoles which enlarge and crowd the bacteria and remaining contents against the inner cell are common in this tissue.

7. Vascular bundles are formed in the nodule, surrounding the bacteroidal cells and connecting with the xylem and phloem of the root. The vascular system develops from the cortical parenchyma by the formation of procambial strands. The vascular bundles are composed of xylem surrounded by phloem.

8. New xylem is continuously added to the vascular bundles of the soybean and cowpea. The vascular bundles of the soybean and cowpea unite at the apex, whereas in alfalfa, sweet clover, and vetch they do not unite.

9. In the soybean nodule a layer of sclerenchyma cells surrounding the bacteroidal and vascular tissues develops which limits the growth of the nodule. This layer of sclerenchyma tissue develops from the cortical parenchyma. It is not found in the cowpea, alfalfa, sweet clover, and vetch nodules.

10. Starch grains are present in abundance in the uninfected cells in the bacteroidal tissue and around the vascular bundles.

11. Filamentous fungi, which appeared to be parasitic because of their invasion of living cells, were found in the nodules. These fungus hyphae resemble the infection strands and may have been mistaken as such by earlier investigators.

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RELATIVE EFFECTIVENESS OF CONTROLLING DIFFERENT PHYSIOLOGIC RACES OF BUNT BY SEED DISINFECTION[1]

J. FOSTER MARTIN and RODERICK SPRAGUE[2]

THE fact that physiologic races of *Tilletia tritici* (Bjerk.) Wint. and *T. levis* Kuhn differing in pathogenicity exist in the Pacific Northwest was first reported by Stephens[3] in 1927. It was at once recognized that this greatly complicates the program for breeding smut-resistant wheat varieties and it is conceivable that it may make seed treatment more difficult. Such would be the case, for example, if it were found that physiologic races respond differently to seed treatment.

It seemed desirable to determine whether such is the case and experiments with this objective in view were begun in 1930. Since then, Holton and Heald[4] found some evidence to support the belief that copper carbonate controlled certain races better than others. The purpose of this paper is to report the results of the experiments begun in 1930. Petit[5], however, reported in 1931 that various antiseptics had a similar effect on each of five bunt strains which he tested.

MATERIALS AND METHODS

Experiments were conducted at Pendleton, Ore., in 1930, 1931, 1934, 1935, and 1936, and at Corvallis, Ore., in 1935 and 1936. The bunt races were selected on the basis of differences in pathogenicity. The race numbers are those assigned by Rodenhiser and Holton[6] with the exception of CL-27, CL 92, CT-28, and CT-117. These are collections made in eastern Oregon which have not been definitely classified.

Clean seed of Hybrid 128 and Goldcoin wheat was used for the experiments at Pendleton in 1930 and 1931 and of Hybrid 128 in all other experiments. Single 16-foot rows were used at Pendleton except in 1936. At Corvallis in 1935 and 1936 and at Pendleton in 1936, five 8-foot rows of each treatment were grown. Infection percentages were based on head counts, there being 300 to 700 heads in the 16-foot rows and about half this number in the 8-foot rows.

[1]Contribution from the Division of Cereal Crops and Disesaes, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Oregon Agricultural Experiment Station, Corvallis, Ore. Technical Paper No. 268 by approval of the Director of the Oregon Agricultural Experiment Station. Received for publication February 2, 1938.

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[6]RODENHISER, H. A., and HOLTON, C. S. Physiologic races of *Tilletia tritici* and *T. levis*. Jour. Agr. Res., 55:483-496. 1937.

For the experiments at Pendleton prior to 1936, the seed was heavily coated with bunt spores and the excess screened off. At Corvallis in 1935, 1 part by weight of inoculum to 100 parts of seed was used. Seed for Corvallis and Pendleton in 1936 was inoculated together, using 1 part inoculum to 200 parts of seed. The disinfectants were applied at the rates specified in Table 1. Only results from those disinfectants which are or have been commonly used by farmers for treating wheat are given. Several additional disinfectants were included at Pendleton in 1930, 1931, 1934, and 1935, but since they have not been and are unlikely to be made available for commercial use, and since results with them were similar to those with the disinfectants included in Table 1, they are omitted here.

EXPERIMENTAL RESULTS

Considering first the copper carbonate treatments (both 52% and 18% copper), it will be noted (Table 1) that all races produced approximately equal percentages of smut, except that T-1, T-11, and L-7 at Pendleton in 1934 and T-11 at Corvallis in 1935 appear to have been controlled better by the treatment than other races. However, the untreated checks of these races also produced less smut than others and it seems more reasonable to assume, therefore, that the observed differences were due to differences in virulence of the races rather than to a differential response to copper carbonate. Probably the same explanation applies to the observed differences in the apparent better control of T-1, T-11, and L-7 for the Ceresan treatment at Pendleton in 1934. Race L-4 was less well controlled at Pendleton in 1930 and again in 1934, but in the other trials this was not the case.

New Improved Ceresan at Pendleton in 1936, when applied at the ½-ounce rate, seemed to control T-8 better than the other races, and the difference cannot be explained by differences in virulence as shown by the checks. However, at the 1-ounce rate, there was no difference in the effectiveness of the treatment for different races. Also, in all other tests with New Improved Ceresan, there is no evidence of a differential response to treatment.

Races T-10 and CL-27 produced more smut than did other races at Corvallis in 1935 when treated with basic copper sulfate, but similar differences did not appear in other tests.

Copper sulfate and formaldehyde effected good control in practically all cases and there are no differences between races that cannot easily be attributed to random errors or differences in corresponding untreated checks.

Altogether, the data here presented supply no convincing evidence that certain races are more or less easily controlled than others. This is true regardless of the fungicide used, except as such differences may be related to differences in virulence of the inoculum as shown by the untreated checks. A few profusely tillered smutted plants from seed that escaped the toxic action of the disinfectant may considerably increase the percentage of smutted heads.

These studies do not apply to conditions where the smut spores are present in the soil. Seed treated with the common disinfectants and planted on High Prairie, Wash., in 1937, on soil infected with spores of a race of *Tilletia tritici* which causes extreme dwarfing of the plants,

TABLE 1.—*Relative efficiency of various seed disinfectants in controlling different physiologic races and collections of bunt.*

Station and year	Rate of treatment per bushel, ounces	Percentage of bunted heads																
		Hybrid 128												Goldcoin			
		T-1	T-8	T-9	T-10	T-11	CT-28	CT-117	L-4	L-7	L-8	CL-27	CL-92	Average	T-8	T-9	L-4	Average
		Check, Not Treated																
Pendleton 1930	—	—	80.1	76.8	—	—	—	—	64.1	—	66.3	—	—	71.8	75.8	—	77.1	76.5
1931	—	—	48.0	52.2	—	—	—	—	74.9	—	—	—	—	58.4	33.5	46.7	64.5	48.2
1934	—	28.8	66.9	78.9	83.3	24.7	—	53.8	83.0	44.3	—	—	—	58.0	—	—	—	—
1935	—	80.3	74.1	75.6	87.3	80.7	—	84.8	77.8	80.0	—	—	—	80.1	—	—	—	—
1936	—	—	88.6	—	—	72.3	77.7	—	—	82.8	—	80.4	—	80.4	—	—	—	—
Corvallis 1935	—	—	—	—	76.8	67.1	91.8	—	—	89.0	—	89.1	80.5	82.4	—	—	—	—
1936	—	—	81.6	—	—	76.6	83.2	—	—	80.9	—	82.6	—	81.0	—	—	—	—
		Copper Carbonate (52% copper)																
Pendleton 1930	3	—	4.0	5.4	—	—	—	—	7.1	—	8.0	—	—	6.1	5.3	—	6.9	6.1
1931	3	—	4.1	3.0	—	—	—	—	6.2	—	—	—	—	4.4	1.6	2.5	1.6	1.9
1934	3	7.8	17.1	24.1	18.3	5.2	—	3.6	25.4	6.0	—	—	—	13.4	—	—	—	—
1935	3	21.8	3.4	10.6	14.6	19.0	—	8.6	5.2	8.8	—	—	—	11.5	—	—	—	—
1936	2	—	6.2	—	—	23.9	21.7	—	—	16.9	—	10.4	—	15.8	—	—	—	—
Corvallis 1935	2	—	—	—	13.8	1.4	15.7	—	—	12.9	—	19.1	14.0	12.8	—	—	—	—
1936	2	—	0.8	—	—	2.1	5.0	—	—	4.0	—	0.1	—	2.6	—	—	—	—

Copper Carbonate (18% copper)																			
Pendleton	1930	3	—	6.9	3.9	—	—	—	—	13.9	—	6.1	—	—	7.7	10.5	—	5.9	8.2
	1931	3	—	2.8	7.5	—	—	—	—	6.7	—	—	—	—	5.7	4.5	2.1	4.9	3.8
	1934	3	6.9	26.5	17.7	26.7	5.7	—	10.7	31.3	4.4	—	—	—	16.2	—	—	—	—
	1935	3	42.3	6.1	14.2	32.5	16.4	—	27.8	12.2	11.7	—	—	—	20.4	—	—	—	—
	1936	2	—	20.9	—	—	18.9	17.9	—	—	26.4	—	10.8	—	19.0	—	—	—	—
Corvallis	1935	2	—	—	—	33.0	7.9	47.3	—	—	35.5	—	31.1	33.3	31.4	—	—	—	—
	1936	2	—	1.9	—	—	1.3	2.8	—	—	6.4	—	0.9	—	2.7	—	—	—	—
Ceresan																			
Pendleton	1930	3	—	9.1	4.3	—	—	—	—	12.0	—	3.0	—	—	7.1	4.6	—	7.1	5.9
	1934	3	4.0	17.7	8.5	17.3	2.9	—	6.1	20.5	5.2	—	—	—	10.3	—	—	—	—
	1935	3	17.8	4.2	11.2	12.7	3.8	—	8.8	4.3	4.3	—	—	—	8.4	—	—	—	—
New Improved Ceresan																			
Pendleton	1936	½	—	2.4	—	—	19.1	18.3	—	—	17.6	—	6.2	—	12.7	—	—	—	—
Corvallis	1935	½	—	—	—	1.4	1.5	4.1	—	—	4.1	—	4.1	0.7	2.7	—	—	—	—
	1936	½	—	0.0	—	—	2.1	2.6	—	—	3.4	—	0.1	—	1.6	—	—	—	—
Pendleton	1936	1	—	0.3	—	—	1.4	1.1	—	—	0.9	—	0.0	—	0.7	—	—	—	—
Corvallis	1936	1	—	0.0	—	—	0.1	0.0	—	—	0.4	—	1.2	—	0.3	—	—	—	—
Basic Copper Sulfate																			
Corvallis	1935	3	—	—	—	15.0	3.4	9.2	—	—	4.9	—	14.4	10.7	9.6	—	—	—	—
	1935	2	—	—	—	7.1	7.2	18.2	—	—	12.6	—	12.7	11.4	13.2	—	—	—	—
	1936	2	—	1.2	—	—	0.7	1.9	—	—	0.7	—	0.0	—	0.9	—	—	—	—
Pendleton	1936	2	—	6.8	—	—	6.1	8.5	—	—	6.3	—	2.5	—	6.0	—	—	—	—
Copper Sulfate*																			
Pendleton	1936	—	—	0.9	—	—	0.7	0.0	—	—	0.6	—	0.5	—	0.5	—	—	—	—
Corvallis	1935	—	—	—	—	4.1	0.4	0.6	—	—	0.0	—	1.3	1.9	1.4	—	—	—	—
	1936	—	—	0.0	—	—	0.3	0.6	—	—	0.0	—	0.0	—	0.2	—	—	—	—
Formaldehyde†																			
Pendleton	1936	—	—	0.0	—	—	0.0	0.0	—	—	4.5	—	2.3	—	1.4	—	—	—	—
Corvallis	1936	—	—	0.0	—	—	0.0	0.2	—	—	0.4	—	0.2	—	0.2	—	—	—	—

*One pound each of copper sulfate and common salt to 5 gallons of water followed by a lime bath.
†Solution made up of 1 part formaldehyde to 320 parts of water.

gave results similar to those mentioned by Tingey and Woodward[7] in which seed treatment did not prevent infection by spores in the soil.

SUMMARY AND CONCLUSIONS

This paper reports results of 5 years' experiments in Oregon to determine whether some of the 12 physiologic races and collections of bunt (*Tilletia* spp.) tested could be more efficiently controlled than others by seed disinfection.

Under the environmental conditions at Pendleton and Corvallis, there were no consistent differences in relative effectiveness of controlling any of the races of bunt tested. The apparent relative efficacy of control of certain races shifted from one year to another. These differences are attributed to chance and to excess proliferation of "escaped" smutted plants. The greatest differences were noted where control was not good, which also may be attributable to greater chance fluctuation. A positive relationship was found between the amount of bunt in the untreated check rows and the effectiveness of control by seed disinfection.

[7]TINGEY, D. C., and WOODWARD, R. W. Relief wheat. Utah Agr. Exp. Sta. Bul. 264. 1935.

WATER REQUIREMENT OF WHEAT AS INFLUENCED BY THE FERTILITY OF THE SOIL[1]

B. N. SINGH and B. K. MEHTA[2]

THE relation between water requirement of crops and the fertility of the soil has been investigated by several workers. Reed (1)[3] found that potash fertilizers had a tendency to reduce the quantity of water needed for unit dry matter production of crop plants, while Hartwell (2) recorded results contrary to those of Reed. Leather (3, 4) came to the conclusion that the addition of fertilizers and manures decreased the water requirement of plants grown in jars but had no marked effect on field plats.

Montgomery and Kiesselbach (5) and Kiesselbach (6) have dealt with the problem of water requirement in America. They found that when manure was added to the soils of different degrees of fertility the water requirement was decreased, the greatest decrease occurring with the least fertile soil.

TABLE 1.—*Water requirement and yield under various manurial treatments.*

Treatment	Transpiration per plant, kilograms	Yield per plant, grams	Water requirement based on	
			Dry matter, grams	Yield, grams
Wood ash	4.228	2.982	460.05	1,497.4
Pigeon extra	4.289	2.984	456.77	1,437.2
Leaf mould	4.881	3.071	440.96	1,589.3
Control	4.078	3.141	449.58	1,497.4
Rape seed cake	5.976	4.377	480.02	1,365.3
Night soil	5.932	4.491	430.15	1,320.8
Ammonium sulfate + potassium sulfate and basal dressing of *C. juncea*	7.712	4.864	459.84	1,585.5
Cow dung	6.870	4.937	447.10	1,391.6
Castor cake	6.351	5.027	416.97	1,263.7
C. juncea	6.613	5.083	433.61	1,301.0
Ammonium sulfate + potassium sulfate	7.809	5.238	435.01	1,490.9
Farm yard manure	6.939	5.312	426.98	1,276.5
Sheep dung	6.395	5.572	365.59	1,147.6
Superphosphate + potassium sulfate	6.556	6.007	373.00	1,091.4
Linseed cake	7.830	6.505	400.94	1,203.7
Neem (margosa) cake	6.517	6.719	319.01	969.9
Safflower cake	8.060	6.813	389.94	1,183.0
Superphosphate + ammonium sulfate	10.320	9.695	345.46	1,064.4

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication February 3, 1938.

[2]Director and Associate, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 398.

Singh, *et al.* (7) and Singh and Singh (8) have recently presented some results on the water requirement of crops in India, but aspects other than manuring were investigated.

In the present paper are presented some data obtained in connection with an attempt to find a quantitative relation between water requirement and soil fertility. A variability in the soil fertility was in-

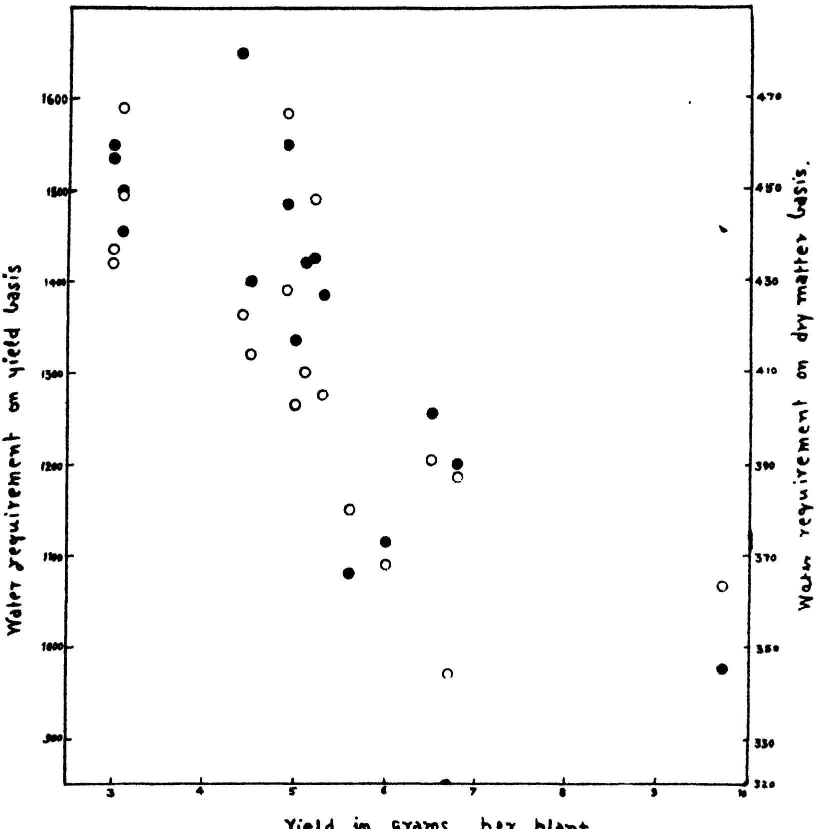

FIG. 1.—Correlation between yield and water requirement. Dots refer to water requirement on the basis of total dry matter production, whereas the circles represent that calculated on the basis of yield of grain.

duced by the application of different manures, both inorganic and organic, in concentrated as well as in bulky forms. The yield of wheat under various manurial treatments provided a quantitative measure of expressing the fertility of the soil.

The manures selected for experimentation may be roughly classified in four groups, *viz.*, (a) farm yard manure, green manure (*Crotalaria juncea*), leaf mould, and wood ash; (b) night soil, cow dung, sheep dung, and pigeon excreta; (c) safflower cake, rape seed cake, linseed cake, castor cake, and neem (margosa) cake; and (d) ammonium sulfate plus superphosphate, ammonium sulfate plus potassium sulfate,

ammonium sulfate plus potassium sulfate with a basal dressing of *Crotalaria juncea*, and superphosphate plus potassium sulfate.

Earthernware pots 10 by 12 inches in size were selected and glazed on the outside to minimize the loss of manurial ingredients. The organic bulky manures in well-rotted, friable condition were mixed with well-sieved farm soil, a typical loam, in the proportion of 1 to 2 parts, respectively, and the mixture utilized for filling up the pots. Oilcakes were powered first and mixed with the soil in the proportion

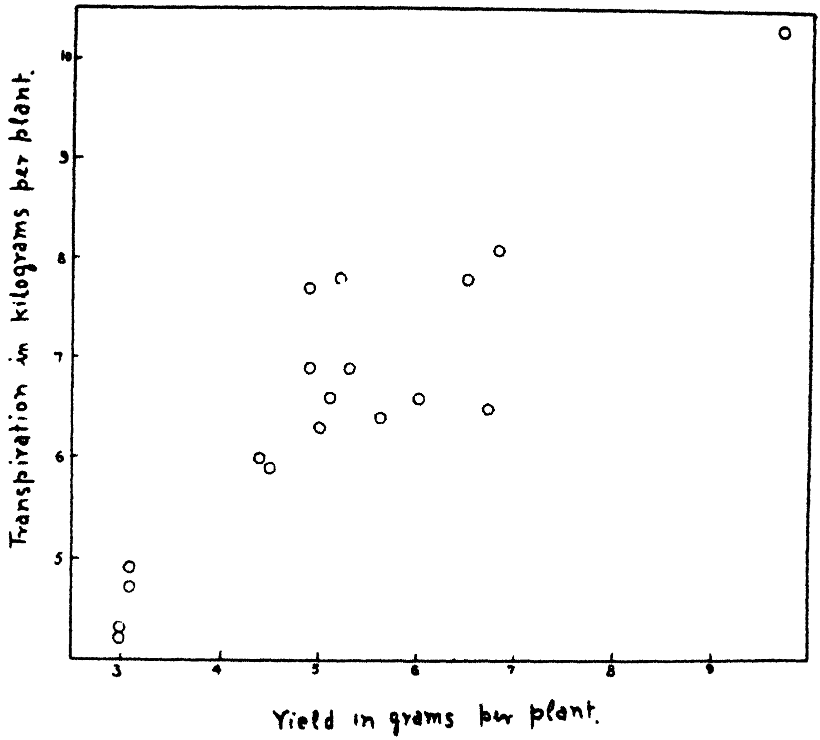

FIG. 2.—Correlation between yield and transpiration

of 4 ounces of manure for each pot. The combinations of chemical fertilizers were in the proportion of 1 to 1 and the total quantity per pot was 8 grams.

Care was taken to ensure that the organic manures had perfectly decomposed before sowing the wheat seed (variety Pusa 4). The method employed for determining the water requirement has already been given by Singh, *et al.* (7).

RESULTS

Data regarding the yield of wheat under various manurial treatments and the corresponding values for water requirement are given in Table 1. It is evident that by means of the manurial combinations

a fairly marked variability was introduced in the degree of fertility of the soil. For example, the yield per plant with wood ash was 2.982 grams as against 9.695 grams with superphosphate plus ammonium sulfate.

Data contained in Table 1 have been presented graphically in Figs. 1 and 2. Fig. 1 shows the relation between the water requirement and yield of wheat. As yield provides a measure of the fertility of the soil, it is evident that there is a correlation between low water requirement and high yield. Fig. 2, on the other hand, shows the relation between the quantity of water transpired in one growing season by one wheat plant and the yield. It is evident that there is a correlation between high water expenditure and high degree of fertility.

To sum up, increasing the fertility of the soil by addition of manures reduces the quantity of water needed for unit dry matter production, but enhances the total quantity of water transpired by the crop.

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SURVIVAL OF WHEAT VARIETIES IN THE GREAT PLAINS WINTERHARDINESS NURSERY, 1930–1937[1]

K. S. QUISENBERRY[2]

A uniform winterhardiness nursery has been grown at from 20 to 30 experiment stations in the Great Plains of the United States and Canada each year since 1919. The purpose has been to obtain information on the relative winterhardiness of new wheats as rapidly as possible. Results of the first 10 years of the experiment have been published.[3]

Data from seven additional years have now been obtained. At the close of each season a mimeographed summary of the current year's data has been prepared and sent to all cooperators. The annual reports are often preliminary, but furnish the current data from the individual stations. Because no period of years summary has been published since 1930 and because of regional interest in the data, the present summary is presented.

Yields were taken at some stations, but as not all nurseries were grown in multiple-row plats and since in many cases yield is directly correlated with survival, the yield data are not given.

SCOPE OF INVESTIGATIONS

The methods employed were substantially the same as in earlier work and have been thoroughly described in the previous reports. In all nurseries the strains were grown in three or more replications. In some cases there were only single rows, while in others there were 3-row blocks. Insofar as possible, all seed was raised at the Kansas Agricultural Experiment Station, Manhattan, Kans. When this source failed to supply sufficient seed of any variety, the deficit was made up from North Platte and Lincoln, Nebr., or from Moccasin, Mont. In most cases seed of new varieties for the first year was grown at the station at which the variety originated.

METHODS

The relative winterhardiness data presented in this report are based, for the most part, on visual estimates of survival in the spring rather than on actual counts. Actual counts are desirable where the seed has been spaced and where large numbers of plants may be counted. In these nurseries the seed was not spaced, and if good stands were obtained, counts would have been very difficult to make. It is felt that in this case an estimate of survival, based on observation at the time growth starts in the spring, gives the most accurate figure on survival.

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[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication February 10, 1938.

[2]Agronomist.

[3]CLARK, J. A., MARTIN, J. H., and PARKER, J. H. Comparative hardiness of winter wheat varieties. U. S. D. A. Cir. 378. 1926.

QUISENBERRY, KARL S., and CLARK, J. ALLEN. Hardiness and yield of winter wheat varieties. U. S. D. A. Cir. 141. 1930.

TABLE 1.—*Annual and average percentage of survival of 66 varieties of winter wheat grown in the Great Plains winterhardiness nursery during one or more years from 1930 to 1937 and the percentage of Kharkof (C. I. 1442) for the period from 1920 to 1937.**

Variety	State or hybrid No.	C. I. No.	Percentage survival in 1930	1931	1932	1933	1934	1935	1936	1937	Weighted average %	Kharkof same years, %	No. station years	Percentage of Kharkof	1920–37 No. of station years	1920–37 Percentage of Kharkof
			24†	22†	26†	20†	8†	16†	14†	10†						
Hard Red Winter																
Minhardi×Minturki	Minn. No. 2312	8215	74.9	84.2	71.3	62.8	51.6	—	—	—	71.7	57.5	100	124.7	141	125.2
Turkey×Minessa	—	8887	72.3	84.2	72.1	60.9	49.0	83.4	—	—	72.5	58.8	116	123.3	—	—
Minard×Minhardi	Minn. No. 2272	8218	70.9	83.9	72.0	62.5	48.6	—	—	—	70.6	57.5	100	122.8	121	121.2
Kanred×Minhardi	—	8040	74.7	84.4	71.2	—	—	—	—	—	76.4	62.2	72	122.8	112	119.2
Kanred×Minhardi	—	8042	72.5	84.7	71.3	—	—	—	—	—	75.8	62.2	72	121.9	—	—
Eureka×Minhardi	—	8036	72.2	85.5	70.9	—	—	—	—	—	75.8	62.2	72	121.9	132	120.7
Minard×Minhardi	Minn. No. 2313	8888	70.5	84.8	70.3	—	—	84.1	65.6	63.9	74.0	61.2	112	120.9	—	—
Wheat×Rye	Alberta I–27–11	11503	—	—	—	55.4	40.6	84.7	64.9	—	63.7	52.8	58	120.6	—	—
Minhardi×Minturki	—	8034	71.4	83.3	70.3	—	—	—	—	—	74.6	62.2	72	119.9	150	118.3
Kanred×Minessa	—	8045	—	—	—	61.5	44.3	80.8	61.4	61.4	64.0	53.6	68	119.4	—	—
Turkey×Minessa	Nursery No. 48	11505	—	—	—	57.5	43.6	80.1	—	—	63.2	53.1	44	119.0	—	—
Minard×Minhardi	Minn. No. 2314	8889	69.4	81.8	69.6	58.3	49.0	—	—	—	68.3	57.5	100	118.8	—	—
Yogo	—	8033	70.5	82.4	—	—	—	—	—	—	76.2	64.6	46	118.0	124	119.2
Kanred×Minhardi	19102 IX–5	11726	—	—	—	—	—	—	64.3	63.9	64.1	54.4	24	117.8	—	—
Minturki	Minn. No. 1507	6155	68.9	79.7	68.2	57.9	45.4	79.6	61.8	59.6	67.4	58.0	140	116.2	290	117.7
Minturki×Marquis	Minn. No. 2614	11502	—	—	—	53.6	40.4	82.9	59.1	65.3	61.8	53.6	68	115.3	—	—
Minturki×Turkey	Wis. No. 81–26	11500	—	—	—	56.5	37.3	86.5	55.9	60.0	61.7	53.6	68	115.1	—	—
Wheat×Rye	Alberta I–27–12	11504	—	—	—	54.9	34.6	81.7	—	—	61.0	53.1	44	114.9	—	—
Minturki×Marquis	Minn. No. 2618	11659	—	—	—	—	—	80.7	60.6	58.1	68.0	59.3	40	114.7	—	—
Minturki×Marquis	Minn. No. 2616	11501	—	—	—	52.2	40.8	84.1	58.0	63.6	61.2	53.6	68	114.2	—	—
Minturki×Marquis	Minn. No. 2615	11658	—	—	—	—	—	77.8	61.6	60.0	67.7	59.3	40	114.2	—	—
Turkey	Minn. No. 1488	6152	66.6	80.3	66.6	53.8	40.8	—	—	—	65.0	57.5	100	113.0	250	112.8
Turkey selection	Nebr. No. 1063	10094	—	—	—	—	41.6	79.0	59.6	59.6	63.1	56.1	48	112.5	—	—

Turkey × Buffum	So. Dak. No. II-29-25-4	11739	—	—	—	—	—	—	—	64.7	64.7	57.8	10	111.9	—	—
Turkey × Kanred	B. H. 25-1	11725	—	—	—	—	—	—	62.5	58.2	60.7	54.4	24	111.6	—	—
Minhardi × Marquis	Minn. No. 2551	11657	—	—	—	—	—	78.1	58.8	56.9	66.0	59.3	40	111.3	—	—
Beloglina	—	1543	67.4	76.2	63.1	—	—	—	—	—	68.5	62.2	72	110.1	165	112.8
Cheyenne selection	Nebr. No. 1087	11666	—	—	—	—	—	—	58.6	61.2	59.7	54.4	24	109.7	—	—
Wisconsin sel. 21.25	Wis. No. 21.25	10018	—	70.5	61.8	51.6	36.9	82.6	—	—	63.1	58.4	92	108.0	—	—
Turkey selection	Nebr. No. 1062	10015	—	72.9	64.7	49.6	—	—	—	—	62.9	58.5	68	107.5	—	—
Nebraska No. 60	Nebr. No. 60	6250	60.9	74.9	62.4	50.0	42.9	75.1	55.8	59.0	61.8	58.0	140	106.6	290	107.1
Turkey × Buffum	So. Dak. No. II-29-37-2	11741	—	—	—	—	—	—	—	61.6	61.6	57.8	10	106.6	—	—
Turkey selection	Nebr. No. 1069	10016	—	72.0	61.3	48.6	39.1	77.4	54.0	—	60.9	57.5	106	105.9	—	—
Wheat × Rye	N. Dak. No. 2309	8890	63.3	—	—	—	—	—	—	—	63.3	60.3	24	105.0	—	—
Beloglina selection	North Platte No. 11	8884	59.9	74.1	62.0	—	—	—	—	—	65.0	62.2	72	104.5	—	—
Wheat × Rye (Meister)	—	11403	—	—	—	—	—	—	53.7	60.2	56.4	54.4	24	103.7	—	—
Cheyenne	Nebr. No. 1050	8885	57.9	73.7	61.2	45.8	39.6	74.8	52.1	59.2	59.7	58.0	140	102.9	—	—
Kanred	—	5146	59.9	69.4	61.0	47.0	36.3	78.6	52.6	56.5	59.6	58.0	140	102.8	290	102.9
Oro	—	8220	60.0	71.4	60.1	—	—	—	—	—	63.5	62.2	72	102.1	113	101.2
Turkey × Galgalos	—	11540	—	—	—	—	33.9	74.4	49.6	—	56.7	55.7	38	101.8	—	—
Kharkof	—	1442	60.3	69.3	58.0	47.4	40.5	66.6	51.9	57.8	58.0	58.0	140	100.0	290	100.0
Newturk	—	6935	59.7	—	—	—	—	—	—	—	59.7	60.3	24	99.0	133	98.3
Karmont	—	6700	58.7	—	—	—	—	—	—	—	58.7	60.3	24	97.3	165	99.3
Iowin	Iowa No. 2025	10017	—	62.5	54.1	42.6	32.3	76.9	47.4	—	54.6	57.5	106	95.0	—	—
Ashkof × Minturki	Wis. No. 312.27 28.1-29.13	11724	—	—	—	—	—	—	48.9	55.1	51.5	54.4	24	94.7	—	—
Kawvale × Tenmarq	Nebr. No. 1086	11669	—	—	—	—	—	—	—	53.7	53.7	57.8	10	92.9	—	—
Blackhull selection	Nebr. No. 1093	11737	—	—	—	—	—	—	—	52.9	52.9	57.8	10	91.5	—	—
Kanred × Hard Fed	Kans. No. 2679	11373	—	—	50.2	43.4	31.6	67.8	—	—	50.2	54.9	70	91.4	—	—

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†Number of stations reporting.

TABLE 1.—*Continued.*

Variety	State or hybrid No.	C. I. No.	Percentage survival in								Weighted average %	Khar-kof same years, %	No. sta-tion years	Per-cent-age of Khar-kof	1920–37	
			1930	1931	1932	1933	1934	1935	1936	1937					No. of sta-tion years	Per-cent-age of Khar-kof
			24†	22†	26†	20†	8†	16†	14†	10†						
Hard Red Winter																
Akron selection	Akron No. 7	11660	—	—	—	—	—	—	48.1	50.7	49.2	54.4	24	90.4	—	—
Kanred×Hard Fed	Kans. No. 2673	10092	—	—	—	—	28.9	67.7	41.9	—	50.0	55.7	38	89.8	—	—
P1066–1×Burbank	—	10087	—	—	—	40.0	—	—	—	—	40.0	47.4	20	84.4	—	—
Oro×Tenmarq	Kans. No. 2729	11673	—	—	—	—	—	—	—	48.8	48.8	57.8	10	84.4	—	—
Wisconsin sel. 18–4	Wis. No. 18.4	10019	—	58.0	—	—	—	—	—	—	58.0	69.3	22	83.7	—	—
Quivira	Kans. No. 2628	8886	47.9	52.0	47.8	43.5	31.8	65.6	36.6	—	47.9	58.0	130	82.6	—	—
Oro×Tenmarq	Kans. No. 2728	11672	—	—	—	—	—	—	—	47.5	47.5	57.8	10	82.2	—	—
Kanred×Hard Fed	Kans. No. 2672	10091	—	—	—	32.2	30.8	63.1	—	—	43.2	53.1	44	81.4	—	—
Blackhull	—	6251	45.9	54.3	47.9	35.1	30.0	61.9	34.8	44.5	45.8	58.0	140	79.0	281	78.6
Tenmarq	—	6936	47.1	50.0	50.3	—	—	—	—	—	49.1	62.2	72	78.9	181	83.2
Early Blackhull	—	8856	40.5	—	—	—	—	—	—	—	40.5	60.3	24	67.2	45	70.9
Tenmarq selection	Kans. No. 267	10089	—	—	—	28.0	—	—	—	—	28.0	47.4	20	59.1	—	—
Marquis×Kanred	Hays No. 318	11374	—	—	32.9	—	—	—	—	—	32.9	58.0	26	56.7	—	—
Soft Red Winter																
Lutescens 0329	—	8896	—	—	—	71.6	45.5	87.9	65.5	76.6	71.8	53.6	68	134.0	—	—
Buffum No. 17	—	3330	75.2	—	—	—	—	—	—	—	75.2	60.3	24	124.7	174	124.7
Minhardi	—	5149	70.5	83.0	70.2	60.9	44.9	88.6	65.4	75.3	71.5	58.0	140	123.3	290	124.1
Kawvale	—	8180	54.5	64.5	56.3	—	—	—	—	—	58.2	62.2	72	93.6	93	93.5
Fulcaster	—	6471	45.6	56.4	47.7	38.0	31.4	54.3	29.9	38.2	44.7	58.0	140	77.1	218	75.1

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†Number of stations reporting.

For the most part varieties have been kept in the nursery only long enough to establish their relative hardiness. A few have remained constant to serve as checks and also for studies relating to the causes of winterkilling in different areas and in different years.

At some stations and in some seasons there was no killing and at others killing was complete. It is obvious that in these cases no information was obtained on varietal differences so these data are not included in the averages, thus the data from a varying number of stations are eliminated each year.

There may be some question as to the propriety of averaging data from several stations for a given year, since the causes of winter killing may be different and the data may not be entirely comparable. For the area as a whole, direct freezing appears to be the principal cause of killing, although at a few stations and in some years drouth is an important additional cause. Enough has been learned from detailed studies to justify the belief that for the determination of the relative winterhardiness of the varieties for the area as a whole, no serious error is introduced by using the average of the various stations.

EXPERIMENTAL RESULTS

A summary of the data is presented in Table 1. For each year the number of stations reporting differential killing is shown. This number varied from 8 in 1934 to 26 in 1932. For each variety is shown an average (weighted for number of stations) for the period grown, together with an average for Kharkof (C. I. 1442) for the same period. Because the varieties were not all grown for the same period of years, and to make comparison easy, the relative winterhardiness is presented as a percentage of Kharkof. It is realized that this method may be open to criticism, but it has some merit.

The varieties are separated into hard and soft red winters depending on the character of the grain. Within each group the varieties are listed in order of relative hardiness based on the percentages of Kharkof for the period 1930–37. Some strains were grown in the nursery before 1930 and for these there is given a percentage of Kharkof for years grown between 1920–37. For the most part this figure does not vary greatly from the one for the period 1930–37.

A total of 61 hard and 5 soft red winter wheats were grown during all or part of the period from 1930 to 1937. Of these 66 varieties, 43 were more hardy than Kharkof. Only four varieties, two hard and two soft, had average survivals equal to or better than Minhardi, the hardy check, although several hybrid strains are nearly equal to Minhardi. Among the hard red varieties all of the more hardy strains are of hybrid origin, most of them having Minhardi as one parent. These represent lines which combine winterhardiness with quality and yielding ability for the more northern areas. Fourteen strains are as hardy as or more hardy than Minturki, a commercial variety grown in Minnesota. Of these, nine are hybrids of which Minhardi is one parent and three are hybrids of which Minessa is one parent.

Four wheat × rye hybrids have been tested. Three of these, C. I. 8890, 11503, and 11504, proved to be more hardy than Kharkof, but none shows any rye characters. The other wheat × rye hybrid (Meister's amphidiploid) shows rye characters but is only slightly more

hardy than Kharkof. The factors for extreme winterhardiness present in our best ryes do not seem to have been recovered in any of these hybrid strains.

Three strains of Minturki × Marquis and one of Minhardi × Marquis from Minnesota have been tested. None of these is quite equal to Minturki in hardiness, but all are distinctly more hardy than Kharkof.

Nebraska No. 60, Cheyenne, Kanred, and Oro are commercial varieties, all of which are slightly more winterhardy than Kharkof. Among the commercial varieties less hardy than Kharkof, the following are listed in order of hardiness: Iowin, Quivira, Blackhull, Tenmarq, and Early Blackhull. Blackhull and Tenmarq are about equal in winterhardiness, but Early Blackhull is decidedly tender, being among the least hardy of those tested. Two Oro × Tenmarq strains seem to be slightly more hardy than Tenmarq but decidedly less hardy than Oro. Both of these wheats are resistant to certain races of bunt.

Only four varieties of soft red winter wheat were tested. Lutescens 0329, Buffum No. 17, and Minhardi are all very hardy. Lutescens 0329 has the highest percentage of Kharkof of any variety in the nursery, due in part to a very high average survival in 1933. Since that time its average has been about equal to that of Minhardi. This variety was developed by selection in the U. S. S. R. where it is one of the most hardy wheats. Here it is very late and yields poorly under most conditions. Kawvale, a semi-hard variety, is slightly less hardy than Kharkof, although more hardy than Blackhull and Quivira. Fulcaster is one of the more tender varieties grown.

A study of the data shows that between the tender varieties, such as Early Blackhull, Fulcaster, and Tenmarq, and the most hardy ones, such as Lutescens 0329 and Minhardi, there is a series of wheats possessing gradually increasing degrees of winterhardiness. In a previous publication,[4] it was suggested that varieties could be classified roughly into four groups for winterhardiness, *viz.*, very hardy, midhardy, slightly hardy, and tender. Such a classification is, of course, arbitrary and with the present data rather difficult.

Lutescens 0329, Minhardi, and one or two hybrid strains undoubtedly make up a group materially more hardy than the remainder. Minturki, Turkey (C. I. 6152), Turkey selection (C. I. 10094), and Nebraska No. 60 are less hardy than the first group. A third group would contain varieties about equal to Kharkof in hardiness. Cheyenne, Kanred, Oro, and Newturk can be placed in this group. The tender group would contain Quivira, Blackhull, Tenmarq, Early Blackhull. and other strains with nearly similar survivals. Thus it is seen that the varieties may be grouped in a general way with respect to hardiness, but between the groups mentioned or any other groups that might be made are many strains that could be classed one way or another, depending on variations from year to year.

A large number of hybrids have been made and studied by both state and federal stations with the object of producing wheats containing more winterhardiness. So far no strains are known that are

[4]See footnote 3, Quisenberry and Clark.

more hardy than Lutescens 0329 and Minhardi, and from this standpoint the work has been disappointing. Progress has been made, however, in the combining of hardiness and grain quality and yield. A number of lines are available that are nearly equal to Minhardi for winterhardiness and in addition are hard red winter wheats which give good yields in the more northern areas of the United States and in southern Canada. A constant search is being made for wheats that may have factors for hardiness differing from those now present in hardy wheats.

SUMMARY

A uniform winterhardiness nursery has been grown in the Great Plains of the northern United States and in Canada since 1919. A summary of the data from 1930 to 1937 is presented.

The object of the nursery is to obtain information on the relative winterhardiness of various varieties of winter wheat.

Lutescens 0329, Buffum No. 17, and Minhardi are the most hardy winter wheats available. Some hybrid strains seem to combine quality of grain and yield with relatively high winterhardiness.

In a general way the varieties studied may be placed in four groups for hardiness: Lutescens 0329 and Minhardi and a few hybrid strains in the hardy group; Minturki, Turkey (C. I. 6152), and Nebraska No. 60 in the mid-hardy group; Cheyenne, Kanred, Oro, and Kharkof in the slightly hardy group; and Quivira, Blackhull, Tenmarq, and Early Blackhull in the tender group. Between the extremes the varieties may be arranged in a gradually descending series from hardy to tender.

FERTILITY AS A FACTOR IN RYE IMPROVEMENT[1]

B. D. LEITH and H. L. SHANDS[2]

RYE is highly self-sterile and depends very largely upon the wind for pollination. Only 60 to 80% of the total number of flowers in the head set seed in the field. Both seasonal variations and heritable differences play a part in the low percentage of seed produced. From the agronomic standpoint a knowledge of the variation within lines in their ability to set seed when self-pollinated is important.

The senior author (4)[3] became interested in this problem on finding that during a 3-year study, 33.2% of 29,760 flowers observed did not set seed under field conditions. Undoubtedly the same situation occurs in commercial rye fields and some decrease in yield due to this cause is to be expected. If there are varying degrees of incompatibility in rye, selection and hybridization of the more compatible individuals might reduce the amount of sterility. Reduction of vigor from inbreeding increases the difficulties of the problem.

Close breeding has yielded results of practical value. A selection program of open-pollinated lines was begun in 1922. Starting with selected plump white kernels from a field of Schlansted rye (Wis. Ped. No. 2) selection was continued over a period of five years in open-pollinated head rows for large heads having high fertility and large, plump white kernels. At the end of the five-year period, several head rows were found in which the kernels were large, free from green color, but approximately 2 to 3% were grayish. The plants were vigorous and the heads were medium large and well filled. Seven of the better lines were composited, given the number Wisconsin Pedigree 6, and named Imperial. This variety has been distributed for commercial production. Subsequent tests in yield plats have shown Imperial rye to be as vigorous, as winterhardy, and higher in yield than Schlansted from which it originated.

As close breeding sufficiently intensive to eliminate green kernels apparently did not result in decrease of vigor or lowering of yield, a more intensive inbreeding and hybridizing program of rye was undertaken in which yield was the main objective and high fertility was one of the means to attain it. This paper reports progress over 11 years of selection for high fertility in inbreds and also of hybrids from inbreds. The scope of this experiment does not permit a detailed and complete study of incompatibility. All low fertility lines were of necessity discarded in the progress of this experiment, therefore no data on low fertility selections are available. These results are submitted therefore to show the progress made during 11 years of inbreeding, hybridizing, and inbreeding of hybrids and selection of the more vigorous and highly fertile lines.

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[2]Professor and Assistant Professor of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 418.

OTHER INVESTIGATIONS ON VIGOR AND FERTILITY IN RYE

Several German, Swedish, Russian, and a few American investigators have reported studies on rye fertility, but only a few of the articles, which have much the same scope as this one, will be referred to here.

Brewbaker (1) states that high and low self-fertility appear to be heritable, but that there is considerable variability in the degree of fertility in one year as compared with another. Certain strains appear outstanding in vigor and yielding ability. Some selfed strains are shown to be uniformly vigorous year after year, while others are uniformly stunted and weak.

Peterson (5) shows that lines selfed for a different number of generations and selected for self-fertility gave a progressive increase in self-fertility for several generations and that from the seventh generation onward the average percentage of seed set in the strains remained fairly uniform. Highly fertile selfed strains when crossed and the progeny selfed showed a higher average percentage of seed setting in F_1, F_2, and F_3 than the parents.

Prjanisnikova (6) finds considerable variation in fertility between inbred lines even though many were closely related. After six years of inbreeding no line was free from a tendency to decrease the percentage of seed set. By selection it was possible to maintain the average percentage of seed set over a number of generations though no actual increase was observed.

Krasniuk (2) states that selection of inbreds can eliminate undesirable forms. Some progenies have been obtained through inbreeding which show no trace of depression in any way, in fact exceed the parental population in many respects. One line gave 46% more yield in the sixth inbred generation (1934) than the standard local rye and the average kernel weights were also heavier.

Krasniuk (3) estimates the loss of yield from empty florets in open-pollinated rye to be 25 to 30%. It is possible that this, like some other undesirable features, can be diminished by inbreeding. One of the difficulties in isolating self-fertile lines in hybridization experiments, he states, is the dominance of self-fertility. Material in different stages of inbreeding was examined from the first to the seventh generation. The average fertility of the inbred series increased progressively with the generation of inbreeding, from 8.2% in the first to 26.1% in the seventh.

PURPOSE OF THE EXPERIMENT

The purpose of this experiment in rye breeding was to determine if by inbreeding or hybridization of selfed lines a variety of rye may be produced superior to rye now commonly grown. As rye and corn are both naturally cross pollinated, a procedure similar to hybrid corn breeding seemed a logical approach to rye breeding. However, self-sterility of rye presents a problem not found in corn which is normally self-fertile. Selfing of hybrids, found valuable in corn breeding, has also been tried in this experiment in rye breeding. The objectives may be summarized as follows:

1. To study the effects of inbreeding on rye.
2. To determine the amount of progress that can be made by continued selection within selfed lines, for fertility, yield, vigor, and resistance to disease.
3. To determine the extent of hybrid vigor after crossing certain inbred lines.
4. To determine the effect of inbreeding on vigor and fertility in vigorous hybrids.
5. To obtain, finally, a rye having desirable agronomic attributes which can be maintained through open-pollination.

MATERIALS AND METHODS

SOURCES OF PARENT STOCKS AND HYBRIDS

The rye used in this experiment came from two sources, Schlansted and Abruzzes. The Schlansted was grown at the Experiment Station for several years under the number Pedigree 2. The lines of the Schlansted used in this experiment for inbreeding were chosen from several plants isolated in 1922 and continuously selected in open-pollinated head rows. Seven lines were composited and named Imperial, as noted above. Others of this group were bagged and used in this experiment on inbreeding. Since 1934, all new inbred lines have originated from the Imperial rye. A second source was several inbred selections and crosses within Abruzzes rye which were obtained in 1929 from E. B. Mains who was then at the Indiana Experiment Station. Some of the crosses made in 1932 were between inbred lines from the Wisconsin Pedigree 2 and Abruzzes selections of Mains. The crosses still being carried on from this combination are ×7, ×9, and ×11. All the other hybrids are from crosses between different inbred lines which were originally selected from the Wisconsin Pedigree 2 stock.

TECHNIC OF INBREEDING

Different methods of bagging heads for the purpose of inbreeding were tried, such as covering individual heads in light weight paper or glassine bags; or groups of heads from the same plant with cheesecloth, cellophane, or 12-pound manila bags. The manila bag was found the most satisfactory. At planting time the seeds were spaced about 6 or 8 inches apart in the row. Just before heading, usually the last week in May, a stake about 1 inch x 2 inches x 5 feet was driven in the ground alongside the larger and more vigorous plants. Just before anthesis, heads were bagged and tied to the stake. As the plants grew, the bags were elevated every two or three days and tapped to scatter the pollen inside. The total flowers on each head were counted and from this the percentage of fertility calculated. The lines having the highest percentage of fertility and plumpest and best appearing seed and those that were purest for absence of color were selected for planting the following season.

TECHNIC OF HYBRIDIZING

While some hand pollination was practiced, this plan was discontinued in favor of mass hybridizing. Hand pollination is slow and tedious and gives too few individual parental hybrids and only a small quantity of seed. For mass hybridization a special breeding block was laid out. Seeds were space planted in the row 6 to 8 inches apart and seed of another selection to be used in crossing was planted in the adjacent row a foot away. Planting was so arranged that each line was

adjacent to every other line that was to be crossed. Just before flowering, a stake was driven between every pair of plants chosen for crossing. Only the vigorous plants were chosen for parents. The heads of the two plants were tied together under one bag and the same attention given to raising and tapping the bags as was done with the inbreds. This scheme of cross pollination gave numerous seeds from which, in the following year's crop, the vigorous hybrids could be selected. While no claim can be made as to which were female and male parents, and even crossing would not be assured by this method, yet the procedure afforded an opportunity for producing hybrid material in greater quantities than by hand pollination.

RESULTS OF INBREEDING IN OPEN-POLLINATED RYE

In the selfed lines, segregation of characters other than fertility was observed. Some of these characters are as follows: Dwarfs (Fig. 1); malformed head or leaf; disease reaction; physiological spotting; low vigor; long slender heads; unusually wide heads; broad leaves; narrow leaves; large or small stems; light or dark green plants; leafy plants good for grazing; and size, shape, and color of kernel (Fig. 2). Many of the segregating characters were undesirable; therefore it is evident that selection of plants having agronomically desirable characters would rapidly reduce the number of lines.

FIG. 1.—Dwarfed rye plant. Dwarfed and other undesirable types appear after inbreeding.

Variable kernel size and shape seem to be characteristic of certain inbred lines. In Fig. 2a are shown kernels from sister selections that were apparently still segregating after 10 years of inbreeding. Vigor in vegetative growth of inbreds for the most part is less than in open-pollinated rye. Some of the inbreds were so poor that they could hardly be reproduced; but some of the more promising inbreds approached the vigor of the open-pollinated, as can be noted in Fig. 3.

Field experiments of this nature are always subject to error from causes which cannot be entirely controlled, *viz.*, foreign pollen lodging in florets before bagging; influence of bagging; and various environmental effects, such as excessive heat and rains. As variations due to these factors do not affect all plants alike, it would seem that averages of several lines should be more significant than values based on individual plants.

In 1934 and 1935 several lines were found among the first year inbreds having all heads completely sterile. An estimate was made of the number of these lines.

Table 1 gives the number of flowers observed, the number fertile, and the percentage of fertility for each year of selfing; also the total flowers, the total number fertile, and the average percentage fertility.

TABLE 1.—*Summary of fertility percentage in selfed rye undergoing continuous selection for fertility.*

Year	No. of years selfed	Flowers observed		Percentage fertile
		Total	Fertile	
1926	1	16,953	253	1.5
1927	1	34,301	1,574	4.6
1934*	1	7,198	183	2.5
1935*	1	13,479	424	3.1
1936	1	8,810	436	4.9
1937	1	7,872	392	2.0
Total or average	–	80,613	3,262	4.0
1927	2	14,398	290	2.0
1928	2	130,166	4,995	3.8
1935	2	10,816	512	4.7
1936	2	5,612	143	2.6
1937	2	13,663	524	3.8
Total or average	–	174,655	6,464	3.7
1928	3	23,953	417	1.7
1929	3	81,424	2,150	2.6
1936	3	12,622	1,969	15.6
1937	3	3,943	61	1.5
Total or average	–	121,942	4,597	3.8
1929	4	14,931	188	1.3
1930	4	78,938	2,873	3.6
1937	4	8,840	3,303	37.4
Total or average	–	102,709	6,364	6.2
1930	5	18,534	391	2.1
1931	5	19,356	843	4.4
Total or average	–	37,890	1,234	3.3
1931	6	2,168	101	4.7
1932	6	30,816	8,263	26.8
Total or average	–	32,984	8,364	25.4
1932	7	2,560	13	0.5
1933	7	3,858	986	25.6
Total or average	—	6,418	999	15.6
1934	8	8,538	2,693	31.5
1931	9	7,336	2,084	28.4
1935	9	21,596	8,958	41.5
Total or average	—	28,932	11,042	38.2

*Estimate made of lines completely sterile.

TABLE 1.—*Concluded.*

Year	No. of years selfed	Flowers observed		Percentage fertile
		Total	Fertile	
1932	10	16,944	9,342	55.1
1936	10	7,555	3,042	39.4
Total or average	—	24,499	12,384	50.5
1933	11	284	66	23.3
1937	11	21,028	9,941	47.3
Total or average	—	21,312	10,007	47.0

In Table 2 each selection is considered a line. The frequency distribution of fertility percentage after different years of selfing is shown. Over a period of 11 years the total number of lines studied is 1,216. Even though selection for high fertility was practiced each year, the average fertility count for the first five years did not exceed 6½%. The sixth year the average was raised to 25.4%. The seventh year it dropped to 15.6%, but in the following years it moved slowly upwards until approximately 50% was reached in the tenth and eleventh years. The distribution continues wide throughout the last six years of selective inbreeding. The drop back to the low percent-

TABLE 2.—*Distribution of fertility in lines of rye after different years of selfing.*

No. of years selfed	Fertility classes in percentage and number of lines in each class											Total lines	Average percentage fertile
	0 to 0.9	0.1 to 9.9	10.0 to 19.9	20.0 to 29.9	30.0 to 39.9	40.0 to 49.9	50.0 to 59.9	60.0 to 69.9	70.0 to 79.9	80.0 to 89.9	90.0 to 99.9		
1	242*	152	22	5	3	2	—	-	-	-	-	425	4.0
2	6	179	10	5	2	—	1	-	-	-	1	204	3.7
3	37	171	8	3	1	—	1	2	2	1	-	226	3.8
4	2	100	5	2	3	3	7	4	-	1	-	127	6.2
5	—	67	1	2	—	—	1	-	-	-	-	71	3.3
6	—	12	4	5	4	4	4	-	-	-	-	33	25.4
7	—	4	3	7	2	3	3	-	-	-	-	22	15.6
8	—	1	2	3	3	—	3	1	-	-	-	13	31.5
9	—	3	4	7	11	3	1	1	-	-	-	30	38.2
10	1	2	5	1	7	12	10	8	2	1	-	49	50.5
11	—	2	1	2	2	3	5	1	-	-	-	16	47.0

*Estimated 1934–3

ages of fertility in the tenth year of selfing is due almost entirely to the behavior of ⊗ 26, one of the original lines. In the selections from this line are found one 0, two in the 0.1 to 9.9, and four in the 10.0 to 19.9 classes. This line, only mediocre in fertility, has been

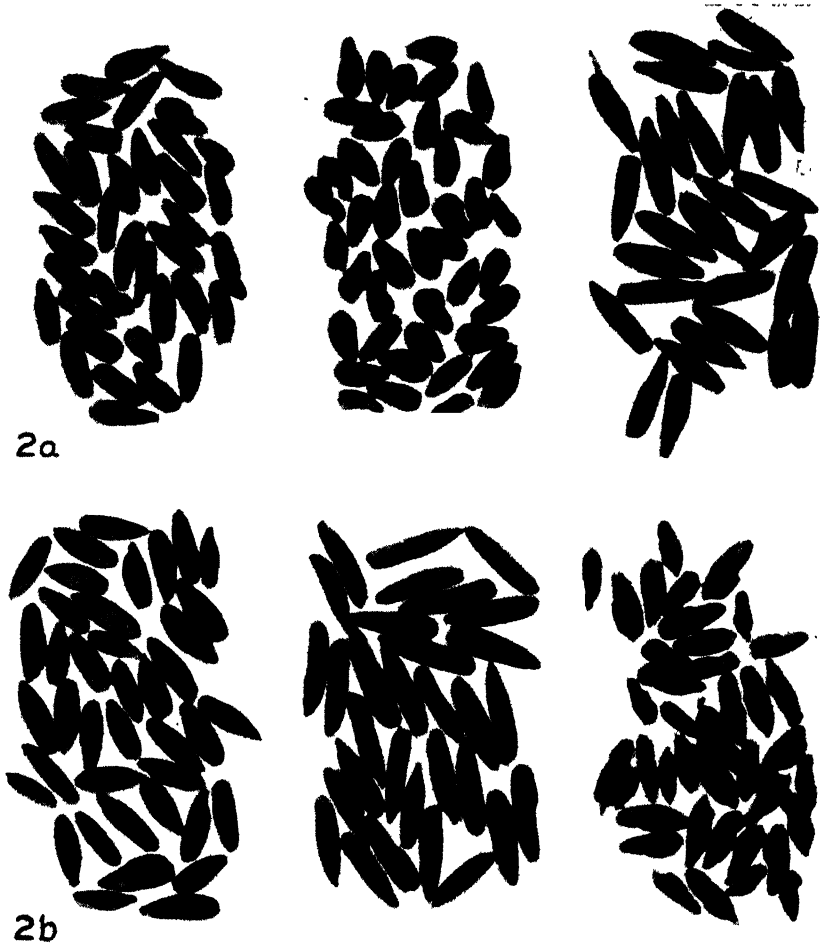

FIG. 2.—Kernels of open-pollinated and inbred rye grown in 1936. (A) 10-year inbreds; left and center groups are sister selections; right, large kerneled inbred. (B) Open-pollinated Imperial rye left; selfed hybrid second generation with large uniform kernels; and right, selfed hybrid fourth generation with poor kernel type.

carried forward because of its ability to make desirable combinations with other selections.

In Table 3 are given the number of original selections in the Schlansted parentage and the number remaining after different lengths of time after selfing. Included in this table is the number of new Schlansted selections introduced into the inbreeding program in 1926, 1927,

1934, 1935, and 1936. Nine of the 260 original selections of 1926 remained in 1927, four in 1928, and by 1933 these remaining lines had

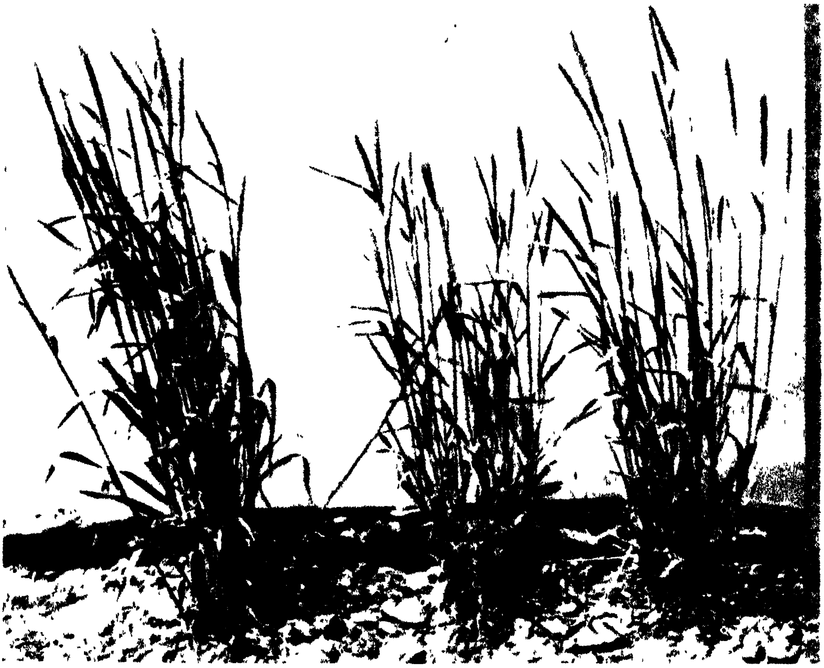

FIG. 3.—Comparison of open-pollinated Imperial rye (left) with two 7-year inbred strains center and right, grown in 1934.

TABLE 3.—*Number of original selections of Schlansted parentage and surviving lines as inbreeding and selection progressed.*

	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
Original selections made in 1926 .	**260**	—	—	—	—	—		—	—	—	—	—
Lines remaining . .	—	9	4	2	2	1	1	0	—	—	—	—
Original selections made in 1927 . .	—	**48**	—	—	—	—	—	—	—	—	—	—
Lines remaining .	—	—	28	17	12	7	3	3	3	3	3	3
Original selections made in 1934*. . .	—	—	—	—	—	—	—	—	**43**	—	—	—
Lines remaining . .	—	—	—	—	—	—	—	—	—	6	6	5
Original selections made in 1935*. . .	—	—	—	—	—	—	—	—	—	**36**	—	—
Lines remaining . .	—	—	—	—	—	—	—	—	—	—	2	2
Original selections made in 1936. . .	—	—	—	—	—	—	—	—	—	—	**24**	—
Lines remaining . .	—	—	—	—	—	—	—	—	—	—	—	6

*Estimate of lines completely sterile.

been dropped because of low fertility. In 1927, 48 selections were again made of the Schlansted, 3 of which are being continued. Even though only three of the original lines are now represented, the 12 reselected progenies from these three lines show 21,028 flowers in 1937, the eleventh year of selection. New introductions of 43 lines in 1934, 36 in 1935, and 24 in 1936 were made from the Imperial which is a selection from the Schlansted. In each case, as was true of the first two years' introductions, the greatest number of lines drop out in the first year of selection due to the fact that there is a marked drop in surviving lines when inbreeding is followed by selection of the highly fertile and vigorous lines.

PRELIMINARY STUDIES OF HYBRIDS OF INBRED LINES

Preliminary studies of hybrids from inbreds were made in 1931, 1932, 1933, and 1934. In 1931 four inbred selections of the Schlansted, Wis. Ped. 2, were crossed. Only two of the F_1 progenies showed hybrid vigor equaling or better than the open-pollinated. In 1932 several crosses were made between inbreds of the Abruzzes and the inbreds of Pedigree 2. Some of the F_1 selections were inferior and some were superior to the open-pollinated rye. In this experiment selection was focused on the superior lines. Further inbreeding of these more highly fertile hybrid lines should determine whether progress can be made through selection of hybrids.

Table 4 gives the number of flowers observed, the number fertile, and the percentage fertility in rye hybrids selfed and continuously selected from one to five years. Certain hybrids are of Abruzzes, others are of Schlansted, and others are a cross between Abruzzes and Schlansted. The hybrids from Abruzzes were made at the Indiana Experiment Station and appear for the first time in this table in 1931 as second year inbreds. Beginning with 1933 new crosses were made each year from the selected inbred lines of the Imperial which were inbred and selected in the years following.

Because the parentage of the lines given in Table 4 differ, general deductions cannot be made on the trend of fertility in the later years of selection. The fourth and fifth year fertility percentages of inbred selections may be reduced by the Abruzzes parentage, which is a southern rye not well adapted to Wisconsin conditions. The average percentage of fertility in the first and second years of selfing and selection in all hybrids is practically the same as that of the tenth and eleventh years' averages of the selected inbreds (Table 1). More work on selection within inbreds of hybrids will be necessary to determine the possibilities of rye improvement along these lines.

Table 5 shows the distribution of fertility in the selections of inbreds from hybrids over a five-year period which is much the same as that of the last four years of inbreeding as shown in Table 2. More years of study on a greater number of lines of wider germ plasm ranges will be necessary to determine whether any advantage is to be gained by inbreeding hybrids in rye.

TABLE 4.—*Summary of fertility percentage in selfed selections from rye hybrids undergoing continuous selection for fertility.*

Year	No. of years selfed*	Flowers observed: Total	Flowers observed: Fertile	Percentage fertile
1933 c†	1	7,696	2,869	37.3
1934 b	1	4,020	1,983	49.3
1935 b	1	10,168	3,155	31.0
1936 b	1	8,336	5,146	61.7
1937 b	1	17,444	9,399	53.8
Total or average		47,664	22,552	47.3
1931 a	2	10,850	5,328	49.1
1934 c	2	36,037	12,413	34.4
1935 b	2	2,414	1,128	46.7
1936 b	2	10,436	5,432	52.1
1937 b	2	8,528	5,496	64.5
Total or average		68,265	29,797	43.6
1932 a	3	8,576	3,065	35.7
1935 c	3	8,339	2,967	35.6
1936 b	3	3,678	981	26.7
1937 b	3	9,454	4,158	44.0
Total or average		30,047	11,171	37.2
1933 a	4	1,038	401	38.6
1936 c	4	11,650	5,235	45.5
Total or average		12,688	5,636	44.4
1934 a	5	2,094	338	16.1
1937 c	5	6,844	2,228	32.6
Total or average		8,938	2,665	28.7

*Filial generation number.
†a = Hybrids of Abruzzes; b = Hybrids of Schlansted; c = Hybrids of Abruzzes and Schlansted.

DISCUSSION

This line of investigation on rye fertility was started with the purpose in mind of producing a highly fertile rye by selection of better inbreds and by crossing these lines of high fertility. Owing to the large amount of material which may be produced from year to year, only those lines showing promise of superiority could be retained for further selection. The fertility of a large number of flowers was observed and numerous lines were obtained, but as selection progressed the number of lines was reduced to a comparatively few. This has been a serious limitation in securing parent stocks for hybridizing.

TABLE 5.—*Distribution of fertility in hybrid lines of rye after different years of selfing*

No. of years selfed	Fertility classes in percentage and number of lines in each class											Total no. of lines	Average percentage fertile
	0 to .09	0.1 9.9	10.0 19.9	20.0 29.9	30.0 39.9	40.0 49.9	50.0 59.9	60.0 69.9	70.0 79.9	80.0 89.9	90.0 99.9		
1	2	13	6	6	12	11	24	19	21	5	2	121	47.3
2	--	3	6	14	14	17	18	22	13	4	3	114	43.6
3	-	8	4	4	13	7	14	2	4	3	1	50	37.2
4	—	—	5	6	5	11	13	5	2	—	--	47	44.4
5	—	5	5	2	4	5	2	1	—	—	—	25	28.7

Bagging heads doubtless disturbs the environmental conditions favorable to seed setting for the plant. Reduced air circulation and lack of sunlight and increased temperature and humidity which occurs under bags, will probably serve to reduce fertility While comparative data are not available, fertility of 30 to 60% under bags of selected inbreds may be comparable to the fertility of open-pollinated stocks. Brewbaker (1) suggests that bagging increased barrenness in Marquis, Mindum, and Emmer wheats, which are normally self-pollinated. Seasonal conditions probably affect the amount of fertility.

The problem of increasing and maintaining fertility in inbreds is somewhat different from that of hybrids. Evidently progress has been made in increasing fertility of inbred lines. Whether continued selection is necessary to keep up the fertility has not yet been answered by this work. Selection within inbreds of hybrids has not increased and probably has not maintained the fertility found in the early generations following hybridization.

Selection of certain inbred lines within hybrids may be necessary to stabilize seed setting ability. Variation in seed setting of different lines has occurred in selfed lines of hybrid origin. First year inbreds of hybrid stocks in 1937 show four lines to be consistently high in fertility and three lines to be variable. A similar condition existed in the 1936 one-year inbreds of hybrids; eight lines are high in fertility and apparently stable, while only two lines are low. The high fertility one-year inbred lines in 1936, which were carried over into 1937 as two-year inbreds, were all high in fertility, carrying about the same average percentage as the previous year.

The possibility of stabilizing high fertility in inbreds originating from hybrids is undetermined so far as this investigation is concerned. The percentage fertility has decreased with continued inbreeding (4 to 5 years) in the limited stocks available from Abruzzes crosses or hybrid combinations of Abruzzes and Schlansted inbreds. Inbreds of less duration (2 to 3 years) from Imperial stock have provided some hope that it will be possible to stabilize high seed setting ability in certain lines.

It might be said that the highly fertile lines selected each year were heterozygous, but this would hardly seem to be the case where several different lines showed no high and low segregates in the second year, with the general average percentage approximately the same as that of the year previous.

The work with inbreds from hybrid origin has of necessity been limited in scope and the full range of possibilities may not have been realized. However, the work is being continued in inbreeding from additional open-pollinated varieties. Each season for the past five years some open-pollinated stocks have been inbred so as to broaden the scope and foundation for investigation of inbreeding and hybridization. It will soon be possible to combine the recently purified inbreds with both the long-time inbreds and inbreds that have been partially reduced to homozygosity after hybridization. Even though some hybrids have been disappointing in their performance in the limited amount of second cycle inbreeding, this source of material may become very valuable as stocks for combining in hybrids. Winter-hardy varieties when inbred may influence the outcome of hybridization in a different and more acceptable way than the nonhardy Abruzzes stock. Continued efforts in producing and maintaining inbred lines of a greater range of germ plasm will serve in the future for determining just how much progress may be made in discovering fundamental principles of rye breeding and in determining how best these principles may be applied in rye improvement.

Isolation of different inbred lines and hybrids from stocks on hand thus far have not proved successful in establishing a variety of rye that is as good a producer as Imperial. It must be kept in mind that this variety was in the first place produced by narrowing certain lines and then compositing them. This variety has been consistently the highest yielder at the Experimental Farm and therefore provides a high standard to be surpassed in the breeding program. Compositing several inbred lines may offer desirable means of obtaining a synthetic variety that will have good quality and high production.

Even though the work thus far has not been successful in producing a variety that is equal in qualities to commercial varieties, certain possibilities are still evident. With increased number and types of inbred stocks, there likely will be additional principles to be discovered in rye breeding. The application of some of these principles may lead to a superior open-pollinated rye.

SUMMARY

Vigor in vegetative growth is usually less in the inbreds than in the open-pollinated rye. Many undesirable segregates appeared by inbreeding which were eliminated. After ten years of inbreeding, some lines still show segregation for size and shape of kernel.

Fertility in inbred lines has been increased by selection. In the first five years of inbreeding and selection the fertility average was low, not exceeding 6½%. The last four years it was higher, reaching approximately 50%. The percentage of fertility was distributed widely each year, with greater frequency in the low fertility classes in the early years of inbreeding.

Some crosses showed hybrid vigor and were superior to open-pollinated rye, while others were so inferior that they were discontinued.

The average fertility of the first and second year's selfing and selection of hybrids compares closely with that of the tenth and eleventh years' inbreds. The range of fertility distribution of selected inbreds from hybrids is wide, differing little from that of the last four years' selection of inbreds.

Further experimental work along these lines is necessary to determine the possibility of obtaining inbred selections or hybrid combinations as productive as the best open-pollinated varieties of rye now being grown.

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SEPARATING A GENERALIZED INTERACTION INTO COMPONENTS[1]

W. B. KEMP[2]

BREEDERS are frequently confronted by the need for determining both relative yield and differential responses or interactions of selected strains or varieties of plants. A determination of differential response is desirable (a) for use in determining the significance of differences in yield, (b) for classifying the strains in separate response groups, and (c) as a starting point from which studies may be undertaken to determine the causes for these differences in behavior. The procedures presented here for breaking down interactions are of much assistance in analysis of complex relationships. However, the number of components which are isolated is beyond the number of sets of degrees of freedom available for a determination of their significance. Therefore, it is usually desirable to group similar components before rendering final judgments for those cases in which such minute analysis is desirable in preliminary studies.

Analysis of variance (1)[3] is now an indispensable tool for use in determining significance of differences in yield and seasonal response among varieties and strains of plants. Its use is justified in most cases where one may logically assume that a homogeneous error is common to the observations of all classes. The data are very easily analyzed when observations of similar classes occur with equal frequency. This method of statistical analysis is of particular value when the number of degrees of freedom is great enough to permit isolation of differential responses, such as interactions between variety and season, in addition to "residual error".

When observations of different classes do not occur with equal frequency the data are more difficult to analyze. However, Yates (2, 3) and Snedecor and Cox (4) have presented procedures for dealing with these cases of unequal frequency.

INTERACTION

Such yield interactions as those between variety and rate of planting apparently were observed early in agronomic investigational work. Mooers (5) pointed out definite corn yield interactions between variety and soil fertility. A statistical consideration of this phenomenon was presented by Fisher and Mackenzie (6) in studies of differential response of potato varieties to manurial treatments. Engledow and Yule (7) stressed the necessity for forming some estimate of the extent to which weather conditions may influence relative yields.

It was pointed out by Maskell (8) that variance introduced by variety differences is of importance in establishing general superiority

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[1]Contribution from the Department of Genetics and Statistics, University of Maryland, College Park, Md. Also presented at the annual meeting of the Society held in Chicago, Ill., December 3, 1937. Received for publication February 14, 1938.

[2]Professor of Genetics and Statistics.

[3]Figures in parenthesis refer to "Literature Cited", p. 424.

of one variety over another only when such variance is significantly larger than that introduced by interactions between variety and environment. Even for such generalizations to be valid, the investigation must have sampled various environmental conditions. The attitude presented by Maskell has received general approval and these lower order interactions, when they are considered to be significant, are used as the source of error by which generalized significance of variety differences in mean yield is determined.

It is logical to use a homogeneous interaction with variety as an estimate of error in determining the general significance of variety differences. However, its very nature is such that one may suspect heterogeneity in any significant interaction in an analysis that involves more than two varieties or strains. Therefore, it follows that any interaction may logically be used as an estimate of error only after it has been analyzed into relatively homogeneous components. Each of these components is a logical error for the determination of general significance of differences for those varieties only which contribute to it.

Wheat varieties on test at the Maryland Experiment Station tend to fall into distinct response groups (9). Significant variety-season interactions exist only when wheats of different response groups are included in one analysis

SEPARATING COMPONENTS OF A HETEROGENEOUS INTERACTION

A procedure by which the significance of the contribution associated with each degree of freedom for interaction is determined separately by use of the "t" test has been presented by Immer, *et al.* (10). The problem under discussion here is an evaluation of differential response of two strains within an analysis when more than one degree of freedom is available for a determination of this response. The "t" test is not designed for such an evaluation. Therefore, analysis is carried out in such a way that Snedecor's "F" test may be used.

In Table 1 yields are presented, in bushels per acre, of duplicate plats of four wheat varieties (M, T, C, and B) during a 15-year period. For simplicity, yields are presented at the nearest even bushel. Table 2 shows results obtained by ordinary analysis of variance of these data. The effects of season, variety, and the interaction of season with variety may all be judged significant in size when compared with residual error. However, the contribution due to variety differences is not significantly greater than that due to interaction. Therefore, one might draw the preliminary conclusion that with such great differential responses among these varieties, no one can be judged generally superior to any other. A necessity for modifying this preliminary judgment becomes apparent when yields for variety C are excluded from Table 1 and the remaining figures are subjected to analysis of variance. Then the contribution due to interaction is reduced to insignificance, while the contribution due to variety may be judged significant when compared with this reduced interaction. Obviously, the presence of C has affected in no way true relationships between M, T,

TABLE 1.—*Data from which components of interaction and variety difference are isolated.*

Year	Yields of wheat, bushels per acre, on duplicate plats of four varieties (M, T, C, and B)												
	M_1	M_2	T_1	T_2	C_1	C_2	B_1	B_2	S_M	S_T	S_C	S_B	S
1919	24	26	21	24	18	22	20	26	50	45	40	46	181
1920	32	31	27	29	28	31	28	29	63	56	59	57	235
1921	21	24	21	19	13	12	22	23	45	40	25	45	155
1922	24	20	25	26	25	24	23	28	44	51	49	51	195
1923	38	34	31	32	35	33	35	33	72	63	68	68	271
1924	30	31	31	32	34	37	36	30	61	63	71	66	261
1925	37	36	32	31	40	42	30	35	73	63	82	65	283
1926	38	46	46	43	47	50	41	45	84	89	97	86	356
1927	24	19	16	23	27	31	21	23	43	39	58	44	184
1928	36	33	31	32	40	33	32	36	69	63	73	68	273
1929	34	34	33	33	31	29	36	38	68	66	60	74	268
1930	43	41	43	42	45	45	38	47	84	85	90	85	344
1931	42	42	30	33	41	43	34	38	84	63	84	72	303
1932	22	21	24	23	20	18	23	22	43	47	38	45	173
1933	26	23	20	20	24	25	24	23	49	40	49	47	185
S	471	461	431	442	468	475	443	476	932	873	943	919	3,667

TABLE 2.—*Analysis of variance of the data in Table 1.*

Source	Freedom	Sum of squares	s^2
Total	119	8179.604	——
Season	14	7058.979	504.21
Variety	3	94.704	31.57
SV interaction	42	701.421	16.70
Residual error	60	324.5	5.41

and B. However, its removal from the analysis has served to reverse the judgment relative to these remaining varieties. Therefore, the immediate problem is a determination of those particular variety comparisons which contribute significant interactions. Significances of mean yield differences are determined at the same time in order that the method which is employed may be compared with that used for the "t" test.

Figures in Table 3 are differences between total yields of the two plats for various combinations of two varieties each. Thus 5, for M-T for 1919, is the difference between 24 + 26, or 50 for M, and 21 + 24, or 45 for T, in that year. Among four varieties are six such sets of differences, i. e., $\frac{4\ (3)}{2\ (1)} = 6$.

For isolating interaction between M and T in Table 3, one obtains 720.93 as the sum of the squares of deviations of M-T from the corresponding mean, and divides by 2 times 2 times 2 times 7, or 56. The first 2 results from the fact that differences between two values are used. The second 2 is used because the figures are the sums of two plats per year. The third 2 results from six combinations among which each variety is included three times. The 7 is one-sixth of 42 degrees

TABLE 3.—*Isolating components of variety difference and interaction with season*

Year	M — T	M — C	M — B	T — C	T — B	C — B
1919	5	10	4	5	— 1	— 6
1920	7	4	6	— 3	— 1	2
1921	5	20	0	15	— 5	—20
1922	— 7	— 5	— 7	2	0	— 2
1923	9	4	4	— 5	— 5	0
1924	— 2	—10	— 5	— 8	— 3	5
1925	10	— 9	8	—19	— 2	17
1926	— 5	—13	— 2	— 8	3	11
1927	4	—15	— 1	—19	— 5	14
1928	6	— 4	1	—10	— 5	5
1929	2	8	— 6	6	— 8	—14
1930	— 1	— 6	— 1	— 5	0	5
1931	21	0	12	—21	— 9	12
1932	— 4	5	— 2	9	2	— 7
1933	9	0	2	— 9	— 7	2
Total	59	—11	13	—70	—46	24
$S(X - \bar{X})^2$	720.93	1,264.93	389.73	1,575.33	180.94	1,479.60

One component of s^2 for variety, $M - T = \frac{59^2}{{}^{*}60} = 58.02$

One component of s^2 for interaction, $M - T = \frac{720.93}{{}^{**}56} = 12.88$

*15 = number per column
1 = columns.
2 = differences of two
2 = sums of two plats per year

**7 = one sixth of 42 degrees of freedom
2 = differences of two
2 = sums of two plats per year
2 = six combinations including each variety three times

of freedom. The result, 12.88, is the contribution of differences between M and T to interaction. Table 4 shows the six contributions to interaction which trace to the six columns of differences. Their average, 16.70, is the same as that obtained by ordinary analysis of variance in Table 2.

TABLE 4.—*Separate components of s^2 for error, for variety, and for season as isolated from Table 3.*

Component	Error	Component	Variety difference	Interaction
M	5.33	M, T	58.02	12.88
T	3.03	M, B	2.82	6.96
C	4.37	T, B	35.27	3.23
B	8.90	M, C	2.02	22.59
	— —	T, C	81.67	28.13
	— —	B, C	9.60	26.42
Average	5.41	....	31.57	16.70

As an evidence that the individual components of interaction, like those of variety difference, constitute a heterogeneous set, the individual components of residual error are presented for comparison. Relatively small differences exist among these components because they constitute a homogeneous set.

For a determination of the significance of any one component of interaction found in Table 4, one looks up F for N of 30 and 14 in the .05 table. The interpolated value is approximately 2.03. The product of 5.41 and 2.03 is 10.98. Therefore, any component of interaction as large as 10.98 may be considered significant.

The algebraic sum of 15 differences between M and T for the 15 years is 59 (Table 3). In order to determine significance of such a sum of differences, look up F for 14 and 1 degrees of freedom. Its value in the .05 table is 4.6. Since 12.88 times 4.6 is 59.25, it follows that the contribution to s^2, for variety, as great as 59.25 may be judged significant.

To find the component of s^2 for variety which is contributed by a difference of 59 between M and T, it is necessary to divide 59^2 by 15 times 1 times 2 times 2. The result is 58.02 which is not quite as large as the 59.25 necessary for significance on the basis of a .05 table. These divisor numbers result from the facts that the number per column is 15, the number of columns is 1, each difference in the column is between 2 values, and the number of plat yields added for each sum before differences are obtained is 2.

Table 4 shows the s^2 for variety difference which traces to each of the six sets of differences. Their average is 31.57, the same value which is obtained from normal analysis of variance in Table 2.

Fourteen degrees of freedom for interaction, or one-third of the total of 42, are available for three of six components because there are only three degrees of freedom for variety. That is, if three of the differences for any one year are chosen judiciously, the remaining three are fixed.

An examination of the sets of figures in Table 4 shows that T is clearly lower in yield that M, B, or C. From figures in the same table it may be observed that significance of interaction results chiefly from the fact that C responds to seasons in a way clearly different from the responses of M, T, or B. An examination of the figures in Table 3 shows that interaction between M and T rises to a significant value because of the marked difference in yield in the year 1931 only. Hence, for the present discussion the significance of this value is ignored. In any case its significance is inconsistent with the (M, B) and (T, B) interactions. Varieties M, T, and B belong to one response group, while C belongs to another. The generalized variety season interaction of 16.70 to which C makes the major contribution is not a valid estimate of error for testing M, T, and B. It would seem reasonable to use the average of 12.88, 6.96, and 3.23, or 7.69, as the variety-season interaction of M, T, and B involving two degrees of freedom, while the corresponding interaction between C and this group would account for the uniformly large values of 22.59, 28.13 and 26.42 involving 1 degree of freedom. On separating interaction in this way, 7.69 is judged insignificant between M, T, and B. Therefore, the observed superiority of M and B over T can be assumed to apply generally. On the other hand, the even greater superiority of C over T can be considered as valid for the conditions of the test only because of the very large interaction of 25.71 with which it might be compared for general validity.

CONCLUSION

Briefly, the foregoing extension of analysis of variance offers an opportunity to study the contributions of different variety comparisons to both yield difference and to interaction.

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COST OF BINDWEED ERADICATION BY THE TILLAGE METHOD[1]

J. V. SRB, L. S. EVANS, and F. D. KEIM[2]

IT has been definitely established that field bindweed (*Convolvulus arvensis* L.) can be eradicated by clean cultivation under Nebraska conditions. Information on the cost of this method is meager, however. It is the purpose of this paper to present an analysis of the cost data of actual eradication operations conducted on a field-size scale in two Nebraska counties, Lancaster and York, during the period 1935 to 1937. Since the two investigations differed as to time and locality separate accounts will be given.

TESTS IN LANCASTER COUNTY

The studies in Lancaster County were made in seven fields in 1935 and 1936. The soils were of the Waukesha and Wabash series, ranging from silt loam to clay loam. All fields were summer tilled for two years. They varied in area from 1 5 to 6.1 acres. Their initial infestation with bindweed varied from medium to heavy and had been established for not less than five years.

In preparation of the fields for cultivation, all rubbish and excess plant growth were removed or burned and where necessary the fields were plowed. The cost of original plowing was excluded from all computations in the Lancaster County fields. In the tillage operations a 10 20 tractor, a duckfoot cultivator of 7½ feet width, and a student operator were employed. The duckfoot cultivator was run at a depth of 3 to 4 inches and at intervals when the plants had made a growth of 4 or 5 inches.

The extent of growth permitted following the emergence of plants was based on the findings of Kiesselbach, Petersen, and Burr.[3] As early as 1924, these workers found that the number of necessary tillage operations could be reduced by permitting slight growth of the plants. Frequent tests were made to see that all plants were severed below ground. Sharp and liberally over-lapping shovels were found effective in preventing the survival of any of the shoots following each tillage.

Accurate and complete records were kept on all operations and results connected with the eradication process. The percentage of reduction of the infestation on the fields was not based on actual counts but on visual estimates, because numbers or counts do not

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[3]KIESSELBACH, T. A., PETERSEN, N. F., and BURR, W. W. Bindweeds and their control. Nebr. Agr. Exp. Sta. Bul. 287. 1934.

always indicate the vigor of plants nor do they adequately measure the effectiveness of a treatment. This viewpoint is in accord with that of Crafts.[4]

To arrive at the cost of tillage per acre, the expense of operating per hour was first established. Table 1 presents data showing the cost of farm implements and their operation reduced to an hour basis. This includes fuel, oil, interest on investment, depreciation, repairs, and operator's wages. The total cost of operating the equipment was $0.70 per hour. The equipment used according to the duty of the machines should have averaged 2.3 acres per hour. Table 2, which records in detail the work done on the seven fields, shows an average of 2.05 acres actually cultivated per hour. The cost of cultivation per acre on these same fields was $0.34. No allowance is made for traveling to and from the fields.

TABLE 1.—*Data showing the cost of farm implements and their operation in Lancaster County, Nebraska, reduced to an hour basis, 1935–36.*

Item	Cost per hour
TRACTOR: Cost $960.00	
Expense of operating tractor:	
Fuel, 9c per gal.	$0.171
Oil, 20c per qt.	0.0765
Interest, basis of 1,300 hours yearly operation	0.044
Depreciation, basis of 1,300 hours yearly operation ($96.00 year)	0.074
Repairs, basis of 1,300 hours yearly operation ($40.00 year)	0.034
Operator's time	0.250
Total cost	$0.6495
CULTIVATOR: Duckfoot, sweep of 7½ feet Cost $86.05	
Expense of operating cultivator:	
Interest, Basis of 1,300 hours yearly operation	$0.039
Depreciation, Basis of 1,300 hours yearly operation	0.0044
Repairs, $10.00	0.0077
Total cost	0.0511
TOTAL COST:	
Tractor per hour	$0.6495
Cultivator per hour	0.0511
Grand total per hour	$0.7006

As shown in Table 2 the infestation on the seven fields was reduced 98 to 100% by the two years of clean cultivation. When a reduction of more than 98% was reached on any field it was considered machine-through. The few remaining plants were treated with sodium chlorate or were hoed. The total cost of spraying 100 plants with sodium chlorate in this follow-up treatment was found to be $0.29.

[4]CRAFTS, A. S. Factors influencing the effectiveness of sodium chlorate as a herbicide. Hilgardia, 9:1935.

TABLE 2.—*Cost of clean tillage for the bindweed control of seven fields in Lancaster County, Nebraska, 1935–36.*

Field No.	Area acres	Date of plowing, 1935	Cultivations		Calculations on an acre basis			Infestation	
			First year, 1935	Second year, 1936	Cultivations per hour	Cost single cultivation per acre	Total cost per acre	Original	Reduction in two years, %*
1	1.5	June 14	10	1	2.02	$0.35	$3.80	Spotted	100
2	3.5	June 17	12	10	2.04	0.34	7.57	Heavy	99
3	3.5	June 15	14	14	2.11	0.33	9.32	Heavy	99
4	6.1	June 26	12	9	2.17	0.33	6.84	Spotted	99+
5	1.5	July 1	10	5	2.09	0.34	5.04	Medium	99+
6	1.5	July 16	11	11	2.14	0.33	7.19	Medium	99
7	5.6	June 27	10	14	1.78	0.39	9.43	Heavy	98
Average	3.3	—	11	9	2.05	0.34	7.03	—	—

*Based on stand of May 20, 1937

It is interesting to note in Table 2 the variation in number of cultivations required in different fields during the second year and the difference in cost of eradication. The lowest cost occurred in field No. 1 amounting to $3.80 per acre and the highest in field No. 7 with $9.43.

TESTS IN YORK COUNTY

The study made in York County in 1936 and 1937 was on a gently rolling field of approximately 39 acres of the Hastings silt loam series. The field was almost solidly infested with field bindweed when clean tillage was begun April 29, 1936, by plowing the field to a depth of 7 inches. Corn stalks were removed by raking and burning before the land was plowed. Cultivations were made thereafter to a depth of 4 inches with a duckfoot cultivator 8½ feet in width equipped with 10- and 12-inch shovels which allowed an overlap of 2 or 3 inches. This lap was important because it prevented plants from slipping through and remaining unsevered. The plants were allowed to make three to four days growth above ground between cultivations.

The field was blank-listed at the end of the first season to reduce soil blowing. The first plants emerged the following spring about April 21 and the lister ridges were thrown in at that time with a "go-dig" and the duckfoot cultivator was used during the remainder of the season until September 16, 1937, when the field was seeded to wheat. It was estimated at that time that 5% of the original stand of bindweeds remained. The field will be cultivated after wheat harvest in 1938 in an attempt to destroy the remaining plants.

Table 3 shows that the mean cost of a single cultivation per acre was $0.32 in 1936 and $0.34 in 1937. The total cost of 32 cultivations over the two-year period was $10.34 per acre. These cost figures include the original plowing and the blank-listing in the fall of 1936

and throwing in the ridges in the spring of 1937 in preparation for the use of the duckfoot cultivator. They also include the operator's time valued at 25 cents an hour. Depreciation on the tractor and cultivator are also included, but since the tractor was used in operating the remainder of the farm, it was arbitrarily agreed that interest on the investment and taxes would not be charged against this tillage.

TABLE 3.—*Showing the average cost per acre of clean cultivation on the 39-acre field in York County, Nebraska, 1936–37.**

Item	1936	1937	Total
Number of cultivations†	20	12	32
Acres cultivated	772	463	1,235
Acres per hour	1.91	2.20	—
Operating expenses (fuel, oil, repairs)	$2.14	$1.14	$3.28
Depreciation on machinery	1.54	1.55	3.09
Labor (25c per hour)	2.62	1.35	3.94
Total cost per acre	6.30	4.04	10.34
Cost per cultivation per acre	0.32	0.34	0.32

*Figures include original plowing, blank-listing, and throwing in lister ridges.
†Average interval between cultivations was 10 days in 1936 and 13 days in 1937

DISCUSSION

COST IN TWO LOCALITIES COMPARED

In York County the average cost per cultivation per acre was $0.32 over the two-year period as compared with $0.34 for the seven fields in Lancaster County. This difference may be due in part to the larger equipment and the larger field in York County which permitted greater economy in each operation.

Despite the fact that the experiments were conducted under dissimilar conditions, the cost per cultivation per acre is in reasonably close agreement in the two studies. The difference in cost of cultivation suggests that by an increase in size of equipment the cost per cultivation may be somewhat reduced.

Additional factors which may affect the output per hour and therefore the total cost of cultivation are soil structure, skill of operator, amount of organic matter in soil, and the amount of trash or plant residues present on the surface.

Because of lack of suitable equipment the fields were not cultivated until after June 15, 1935, in Lancaster County. It was not determined from these experiments whether complete eradication at the end of the second year might have been effected if cultivation had begun as soon as the bindweed plants emerged in the spring. It is apparent, however, that this delay in starting cultivation accounted, in part at least, for the fact that the average number of cultivations was 22 over the two-year period as compared to 32 cultivations during two full seasons in York County. The data should serve, however, to calculate the mean cost of cultivation per acre.

When the work of eradication by the tillage method was started on a field in Lancaster County, the fence rows, if infested, received immediate treatment with sodium chlorate. As in the fields, weeds and rubbish were first removed. Individual plants were sprayed with a

sodium chlorate solution (1 pound of sodium chlorate to a gallon of water). The application was made with a small hand sprayer. Only a small amount of material and labor were required to clean the fence rows of bindweed.

PROPOSED FOLLOW-UP TREATMENTS

Individual plants remaining after about 98% of the original stand have been killed by cultivation may be treated more economically by cutting off with a hoe or by individual treatments with a small quantity of sodium chlorate than by cultivating the entire field.

Careful attention should be given to field management following eradication to prevent the re-establishment of a stand of bindweed by seed carried over in the soil or present in the fertilizer or in the crop planted. Cropping practices which include intertilled crops will aid in controlling young seedlings if they are not allowed to become well established before cultivation.

SUMMARY

With the standard tillage equipment used in these bindweed eradication studies the total cost per acre per cultivation ranged from 32 to 34 cents. An interval of 4 to 6 days of growth between cultivations is suggested as a means of reducing the total number of cultivations required and therefore the cost of bindweed control. Excess trash should be burned before beginning clean cultivation with a duckfoot cultivator.

Two successive years of clean cultivation eradicated 95 to 100% of the original stand of bindweed. Further supplementary treatment is necessary to complete eradication.

The average interval between cultivations in York County was 10 days the first year and 13 days the second. In Lancaster County the average interval was 8 days in 1935 and 10 days in 1936.

In York County the field received a total of 32 cultivations in 1936 and 1937. The seven fields included in the Lancaster experiment averaged 22 cultivations during the two-year period 1935–36.

It appears from these preliminary investigations that bindweed can be eradicated by the tillage method under ordinary Nebraska field conditions for approximately $10.00 per acre.

CHARACTER ANALYSIS OF WINTER WHEAT VARIETIES[1]

W. W. WORZELLA and G. H. CUTLER[2]

NEVER before was the task of the wheat breeder more exacting and difficult than it is at the present time. Today he must not only develop varieties possessing the ability to give maximum yields, but in addition he must synthesize into the same variety all or nearly all of the major characters that will render it more desirable to the locality and purposes for which it is intended. A complete knowledge, therefore, of all major varietal characters is important and necessary in a wheat-breeding program. Obviously, such a knowledge is fundamental and basic to an intelligent selection of suitable parental stock. In this paper reference will be made to soft and semi-hard wheat varieties only; however, so far as the underlying principles are concerned, they apply equally to the hard wheats.

In illustrating the procedure followed in this study an analysis is made of 11 characters of 30 varieties of soft and semi-hard winter wheats grown at Lafayette, Indiana, during the five years of 1933 to 1937, inclusive.

MATERIALS AND METHODS

The experiments here reported were conducted on 30 varieties of wheat included in the eastern winterhardiness wheat nurseries planted in cooperation with the U. S. Dept. of Agriculture Bureau of Plant Industry and interested state experiment stations. Each variety was grown under uniform soil conditions, in rod-row plats replicated four times. Numerical data on 10 major characters are reported, namely, winterhardiness, yield, gluten strength, meal color, meal particle size, test weight, kernel size, leaf rust, loose smut, and plant height. Strength of straw was also studied. The data for relative winterhardiness reported as percentage survival were obtained from both field determinations and artificial freezing tests. In the former, estimates were made on each of four replications, while in the latter comparable data were secured on eight separate tests in which seedlings grown in the field in flats and naturally hardened were subjected to a controlled temperature of $-10°$ F for 24 hours in a cold chamber.

Gluten strength was determined by means of the wheat meal fermentation time test as developed by Cutler and Worzella (2, 3, 4)[3]. The carotenoid pigmentation, expressed as carotene in parts per million on finely ground whole wheat meal, was determined spectrophotometrically by the method outlined by Ferrari and Bailey (6) and Ferrari (5). The particle size index was obtained by a modified procedure of the method described by Cutler and Brinson (1). By this procedure, particle size index represents the percentage of material passing through the finer or 270-mesh sieve. Accordingly, a low index indicates large particles of flour usually associated with hard wheats and a high index indicates a fine, smooth flour characteristic of soft wheats.

[1]Contribution from Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Ind. Received for publication February 18, 1938.

[2]Assistant in Agronomy and Assistant Chief in Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 433.

EXPERIMENTAL

A knowledge of both the desirable and undesirable characters of a variety to be used as parental stock is basic to any systematic plant breeding program. Since many physiological characters are greatly modified by soil and climatic conditions, the potentiality of these characters must be determined for the particular locality in which their use is contemplated. The data are shown in Table 1 with the varieties arranged in the order of decreasing winterhardiness as determined by field estimates.

The varieties studied show considerable range for all characters, when grown under Indiana conditions. For example, winter survival in the field varied from 5.2 to 80.4%; yield, 2.5 to 31.2 bushels; gluten strength, 22 to 140 minutes; color or carotene, 1.92 to 4.00 p. p. m.; particle size index, 7.1 to 18.0%. All of the varieties show varying degrees of susceptibility to leaf rust and loose smut. Considerable difference is found in test weight and size of kernel. Some varieties rate low in strength of straw, while others rate very high.

It is of interest to note that the seven varieties on the upper end of the array are rather closely related to hard wheats. Of interest is the fact that, as a whole, they are not only superior in winterhardiness but also they are relatively stronger in gluten, grind coarser, and possess a higher proportion of carotenoid pigments than do the typical soft wheats. At first thought it might seem that these data support the supposition held by many plant breeders that a linkage exists between strong gluten and winterhardiness and weak gluten and non-winterhardiness. However, when we consider the locations under which these varieties were bred and the specific purposes for which they were selected, it seems to help to explain this relationship. First of all, most of these semi-hard wheats were selected under conditions where the winters are rather severe, and with the objective of producing a winterhardy wheat with strong gluten quality. On the other hand, the typical soft wheat varieties as a rule were selected for soft or weak gluten under conditions where rather mild winters prevail. Consequently, the writers believe that the relationship between winterhardiness and quality shown in the above data is the result of selecting varieties which possessed this relationship because of the conditions under which they were grown and the objectives sought, rather than linkage. Among the typical soft wheats, the data show no correlation between winterhardiness and quality.

The soft wheat varieties that are commonly grown and found satisfactory for cakes, crackers, pastry products, etc., possess a definite quality. The white wheats show the weakest gluten or a "time" of 22 to 23 minutes, while the red soft wheats vary in gluten strength from 34 to 53 minutes when grown at Lafayette. Color, or carotenoid pigmentation, varied from 1.92 to 2.87 p.p.m. in the soft wheats. Particle size index varies from 11.2 to 18.0% in the soft varieties, with the majority over 12.5. Since little information is available on quality in soft wheats, it appears that the above data on the various components of quality may be used as a guide in breeding new wheats that are to be used for the same purposes. Milling and baking tests on these varieties are underway in a further study of quality in soft wheats.

TABLE 1.—*Data for 11 characters of 30 varieties of soft and semi-hard winter wheat grown at Lafayette, Indiana, during the 5 years 1933 to 1937.*

Variety	Winter-hardiness, % survival		Yield, bu. per acre	Quality					Disease		Height, in.	Strength of straw
	Field tests	Arti-ficial tests		Gluten time test, min.	Color, carotene in p.p.m.	Particle size index %	Test weight, lbs.	1,000 kernel weight, grams	Leaf rust %	Loose smut†		
Minhardi	80.4	76.6	23.1	68	3.89	11.9	55.9	21.2	47.0	1.4	38	Good
Purkof	79.0	56.5	31.2	140	2.81	8.2	58.3	26.6	31.4	0.5	43	Good
Minturki	78.5	69.8	29.7	89	3.92	11.2	60.2	25.7	40.8	0.9	40	Fair
Kawvale	77.5	61.5	30.4	94	2.41	7.1	59.5	28.0	19.6	0.1	38	Weak
Kharkof	74.8	70.4	21.5	55	3.05	8.0	58.6	25.9	33.8	4.7	37	Fair
Progeny No. 2 (Ill.)	74.1	52.5	27.9	63	4.00	15.4	60.4	23.6	38.8	1.6	41	Fair
Wis. Ped. No. 2*	73.7	60.1	27.9	60	2.60	12.3	59.3	27.7	31.3	0.3	41	Fair
Mich. Amber	69.1	40.9	27.6	53	2.06	11.4	57.5	27.2	38.8	5.6	42	Good
Fulhio	66.2	27.6	29.3	38	2.87	15.4	58.9	30.5	42.2	0.5	42	Good
Fulcaster	66.0	31.7	27.6	40	2.16	12.5	60.1	32.7	45.6	0.8	42	Fair
Purdue No. 1	65.8	34.6	27.9	39	2.41	15.4	56.7	26.2	34.8	9.7	42	Good
Trumbull	65.5	28.8	27.9	38	2.71	14.8	58.7	30.5	40.2	0.2	43	Good
Harvest Queen	65.2	41.2	24.8	47	1.95	12.3	59.4	29.8	53.4	0.5	44	Fair
Junior No. 6	63.7	27.1	29.0	23	1.92	14.0	56.2	30.0	46.0	0.4	40	Stiff
Rudy	63.2	26.6	27.9	38	2.34	12.2	58.9	34.3	41.8	1.1	43	Fair
Medit. Sel.	63.0	29.9	23.0	34	2.46	14.9	59.0	24.3	32.8	1.5	41	Very weak
Poole	62.8	29.5	27.5	42	2.33	11.9	58.0	28.3	41.8	8.0	43	Good
Nabob	62.1	22.2	28.3	35	2.31	13.2	58.3	30.9	46.6	1.0	41	Good
Bald Rock	61.0	31.4	27.7	44	2.12	11.2	58.5	31.5	52.6	3.0	42	Good
Currell	60.6	29.0	26.2	39	2.32	14.2	59.3	27.4	39.8	0.6	41	Weak
Forward	60.3	30.5	29.9	43	2.34	13.3	59.1	31.6	47.8	0.3	42	Good
Gladden	57.0	23.2	29.0	39	2.58	16.2	57.6	27.4	47.2	7.1	42	Good
Nittany	56.7	26.0	27.9	42	2.33	16.1	56.6	32.6	39.4	1.7	43	Weak
Valprize	55.7	26.9	25.4	36	2.46	18.0	56.3	28.9	39.2	0.9	40	Stiff
Red Rock	54.2	23.8	26.1	53	2.08	11.7	57.9	32.8	49.6	10.2	42	Good
Honor	52.4	24.7	28.5	22	2.83	13.9	56.9	28.7	44.6	4.3	41	Stiff
Amer. Banner	51.8	23.2	25.8	23	2.72	14.5	56.8	29.6	49.2	5.0	41	Stiff
Purple Straw	41.7	26.0	18.3	41	2.76	13.9	59.5	25.4	48.2	2.4	38	Good
Leaps	35.6	8.8	18.1	36	2.56	16.8	—	28.9	51.8	0.1	40	Good
Red Hart	5.2	2.0	2.5	—	—	—	—	—	—	—	—	—

*4-year average.

†Average number of loose smut heads per rod row.

The characteristics desired in soft winter wheats in Indiana are high yielding ability, the winterhardiness of Minhardi or Purkof, gluten strength below 50 minutes, particle size index over 12.5, carotene content below 2.6 parts per million, test weight of 60 pounds per bushel, medium to large sized kernel, leaf rust and loose smut susceptibility as near nil as possible, and plants of medium height with the stiffness of straw found in Junior No. 6 or American Banner.

Since most of the desirable characters are dispersed among many varieties, the above character analysis becomes a valuable aid in selecting proper parental stock. It provides the breeder with the evidence he needs in supplying exact data concerning those major varietal characteristics in which he is vitally interested. So vital are these data in insuring ultimate success in breeding for a specific purpose, that a varietal series carried out in a manner somewhat similar to the above description seems so imperative that it might be regarded as an integral part of a wheat breeding program.

SUMMARY

Analyses were made of 11 characters of 30 varieties of soft and semi-hard winter wheat grown at Lafayette, Indiana, during the five years 1933 to 1937, inclusive.

Wheat characters varied considerably in different varieties Winter survival in the different varieties varied from 5.2 to 80.4% in the field and 2.0 to 76 6% under artificial freezing tests; yield from 2.5 to 31.2 bushels; gluten strength 22 to 140 minutes; color or carotene 1 92 to 4 00 p.p.m.; and particle size index 7.1 to 18.0%.

Soft wheat varieties were less winterhardy than semi-hard wheats under Indiana conditions. They possess a weaker gluten, a lower proportion of carotenoid pigments, and also produce a finer flour.

Fundamental data for several characters are presented which may serve as a basis for breeding suitable soft winter wheats.

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EFFECT OF VARIETY AND STAND OF SOYBEANS ON RELATIVE YIELD AND PERCENTAGE OF TOTAL NITROGEN IN TOPS AND ROOTS[1]

W. B. ANDREWS and MARVIN GIEGER[2]

THE purpose of the experiment reported in this paper was to determine the percentage of the total weight and total nitrogen of the soybean plant contained in the roots of several varieties and the percentage of nitrogen in the tops and roots. From these data conclusions may be drawn as to the relative effect of varieties of soybeans on soil fertility.

Borst and Thatcher (2)[3] found the top-root ratio of Manchu and Peking soybeans at maturity when grown in cans at Columbus, Ohio, to be 13 to 1 and 10 to 1, respectively. Wiancko and Mulvey (4) found 10.9 pounds of nitrogen in the roots of soybeans where 81.8 pounds were found in the tops. Piper and Morse (3) report 165 pounds of nitrogen in the tops of soybeans and 9 pounds in the roots.

Andrews (1) found the yields of the roots of Laredo, Mammoth Yellow, and Otootan soybeans grown in pots to be 13.2 ± 1.01%, 20.2 ± 0.69%, and 19.0 ± 0.68% of the total yield, respectively. The nitrogen contained in the roots was 16.9 ± 1.33%, 20.1 ± 0.62%, and 21.9 ± 1.18% of the total.

Soybeans were also grown in the field and the roots were harvested under an area with a radius of 2.5 feet from the plant (1). The yields of the roots of Laredo, Mammoth Yellow, and Otootan were 6.5 ± 1.21%, 10.7 ± 1.35%, and 7.6 ± 0.82 of the total yield, respectively. The nitrogen contained in the roots was 4.3 ± 0.74%, 6.4 ± 1.18%, and 6.5 ± 0.60% of the total nitrogen.

The data obtained on the yield of roots depend upon the method of obtaining them. When cans or jars are used, the roots are not in a normal environment. When roots are harvested from plants grown in the field, it is too often the case that many of the smaller roots are lost, and, as a consequence, the results are inaccurate and the chemical analyses are not representative. After roots have been obtained, it is very difficult to remove all of the soil from them by washing and, therefore, this presents another factor which causes variation in the results. The data of Andrews reviewed above were so affected.

THE PRESENT EXPERIMENT

The data reported in this paper were obtained from the roots of soybeans which were planted 8 to 10 feet apart in May 1933 on Ochlocknee sandy loam. The soybeans were harvested during the first two weeks of September. The earlier varieties were harvested first. The tops were removed at the surface of the ground, then a trench was dug around each stubble at a distance of 3.5 feet. The depth of the trench was 2 to 2.5 feet. The trench was then filled with water and the roots

[1]Contribution from the Departments of Agronomy and Chemistry, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication February 21, 1938

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[3]Figures in parenthesis refer to "Literature Cited", p. 437.

were washed out by pouring the water onto them. The roots which went deeper than the plowed soil were dug out with a tile spade. The soil settled to the bottom of the trench. The roots were then washed in clean water and the largest pieces of organic matter to which they were clinging were removed. They were then dried, weighed, ground, and analyzed for nitrogen and ash.

The roots thus obtained were from an area of 38.5 square feet. Incidentally, it was observed that only an insignificant quantity of roots was below the plowed soil. The few roots which were lower possessed practically no fibrous branches.

A field of thickly planted Mammoth Yellow soybeans was selected to determine the effect of stand on the ratio of root to total plant weight. The fine and coarse roots were separated by stripping the fine roots off of the coarser roots.

RESULTS AND DISCUSSION

PERCENTAGE OF TOTAL WEIGHT AND TOTAL NITROGEN IN ROOTS OF SEVEN VARIETIES OF SOYBEANS

The ash analyses of the roots were so variable due to the soil which could not be removed from them that the actual yields of the roots were converted into yields containing a uniform ash content of 8%, which is the approximate ash content of soybean tops, and the data are so reported in Table 1. The ash content of the Laredo actually varied from 8.6 to 36.4%.

TABLE 1.—*Percentage of total weight and total nitrogen in soybean roots.*

Variety	Percentage of total weight in roots	Percentage of total nitrogen in roots	No. of plants
Laredo	9.3 ± 0.61	8.6 ± 0.79	6
Otootan	16.0 ± 1.14	15.4 ± 1.21	6
Biloxi	16.1 ± 1.48	15.7 ± 1.13	4
Mamredo	9.4 ± 0.45	7.2 ± 0.46	6
Tanloxi	17.0 ± 0.71	16.4 ± 0.63	6
Delsta	15.8 ± 1.13	14.3 ± 1.01	6
Mammoth Yellow	14.9 ± 1.33	12.8 ± 1.66	6

The data in Table 1 show that the soybeans used in this test may be divided into two groups insofar as percentage of total weight and percentage of total nitrogen in the roots are concerned, namely, group 1, containing Laredo and Mamredo, which has about 9% of the total weight and about 8% of the total nitrogen in the roots; and group 2, containing Otootan, Biloxi, Tanloxi, Delsta, and Mammoth Yellow, which has about 16% of the total weight and about 15% of the total nitrogen in the roots.

The difference in the percentage of the total weight in the roots of the Laredo and that of the Mammoth Yellow is 5.6 ± 1.46. The difference in the percentage of the total nitrogen in the roots of the Laredo and that of Mammoth Yellow is 4.2 ± 1.84. These differences are highly significant. The differences between the percentage of the total weight and percentage of total nitrogen in the roots of the Laredo and Biloxi, Laredo and Otootan, Laredo and Tanloxi, and Laredo and Delsta are greater than the differences between Laredo and

Mammoth Yellow. The differences between these characteristics of Mamredo and any member of group 2 are greater than the differences between Laredo and Mammoth Yellow.

Mammoth Yellow, Mamredo, and Laredo mature at about the same time; the others are later maturing varieties. The Mamredo is assumed to be a natural cross between Laredo and Mammoth Yellow and it has a root system similar to that of the Laredo. The Delsta is a selection out of Mammoth Yellow and has a root system similar to that of the Mammoth Yellow. The Tanloxi is assumed to be a natural cross between Biloxi and Otootan and has a root system similar to that of the two varieties.

EFFECT OF STAND UPON PERCENTAGE OF TOTAL PLANT FOUND IN ROOTS

When Mammoth Yellow soybeans were grown 8 to 10 feet apart, 14.9% of the total weight was in the roots while 30.0% of the plants, when grown in a thick stand, was in the roots. Only one sample was obtained from the thick stand which was grown on a different soil type; however, there were several plants in the sample. The probability that the difference is due to sampling is very small.

PERCENTAGE OF NITROGEN IN TOPS AND ROOTS OF SEVEN VARIETIES OF SOYBEANS

The data in Table 2 show that the percentage of nitrogen in the tops of the seven varieties of soybeans varied from 2 23 to 2.68, while that of the roots varied from 1.91 to 2.26. The percentage of nitrogen in the roots of these soybeans is relatively much higher than most analyses of other varieties which have been reported. This is probably due to the fact that the method used was such that practically all of the fine roots were recovered and to the fact that the data were converted to an 8% ash basis

TABLE 2.—*The percentage of nitrogen in the tops and roots of seven varieties of soybeans*

Variety	Percentage nitrogen	
	Tops	Roots (8% ash basis)
Laredo	2.56 ± 0.074	2.06 ± 0.025
Otootan	2.61 ± 0.042	2 26 ± 0.091
Biloxi	2.23 ± 0.150	2.13 ± 0.078
Mamredo	2.70 ± 0.041	1.91 ± 0.049
Tanloxi	2.55 ± 0.062	2.20 ± 0.022
Delsta	2.65 ± 0.022	2.15 ± 0.052
Mammoth Yellow	2.68 ± 0.014	1.92 ± 0.107

RELATIVE AMOUNT OF FINE AND COARSE ROOTS

The soybean roots obtained from the thick stand were separated into fine and coarse roots by stripping the fine roots off of the coarse roots. The fine roots were 59% of the total roots.

PERCENTAGE OF NITROGEN IN FINE AND COARSE ROOTS

The percentage of nitrogen in the fine roots was 2.59, while that in the coarse roots was 0.87. The percentage of nitrogen in the fine roots of soybeans is sufficiently high for them to decompose without the micro-organisms drawing upon the soil nitrogen; however, the coarser roots should have little immediate effect.

SUMMARY AND CONCLUSIONS

Six varieties of soybeans were grown in the field, each plant spaced 8 to 10 feet apart. The roots were washed out of the soil under a 38.5 square foot area. Practically all of the roots were recovered. In addition one sample of Mammoth Yellow soybean tops and roots was obtained from a thickly planted field. There were sufficient samples in the varietal comparison to apply statistics, but there was only one sample of thickly spaced soybeans. On the basis of the thickly spaced soybeans, the data on the thinly spaced soybeans could probably be doubled. The data show that:

1. The varieties of soybeans studied fall into two groups with respect to their root systems, namely, group 1, containing Laredo and Mamredo, which has about 9% of the total weight and about 8% of the total nitrogen in the roots; and group 2, containing Otootan, Biloxi, Delsta, Mammoth Yellow, and Tanloxi, which has about 16% of the total weight and about 15% of the total nitrogen in the roots.
2. The quantity of roots and the quantity of nitrogen left in a soil by the roots of a good crop of soybeans is too small to affect the following crop materially.
3. The roots of the soybeans grown in a thick stand composed 30% of the total weight of the plant; those of the thin stand composed 15% of the total weight of the plant.
4. Fifty-nine per cent of the roots were fine and 41% were coarse.

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AVAILABLE POTASSIUM IN ORCHARD SOILS AS AFFECTED BY A HEAVY STRAW MULCH[1]

I. W. WANDER and J. H. GOURLEY[2]

IN a recent brief article (8),[3] the authors pointed out the large amounts of available potassium found beneath old straw mulches as compared with adjacent cultivated land. Since then, additional confirmatory evidence has been obtained in a mulched pear orchard on a Mahoning silty clay loam at Strongsville, Ohio. It is our purpose here to present the data on which these observations were based, together with those obtained on a similar orchard soil to which potassium fertilizers have been applied.

Studies were begun in the orchards of the Ohio Agricultural Station in 1928 to determine the need for other elements than nitrogen, particularly phosphorus and potassium. About that time it was noticed that each year there was a definite scorching of the foliage which suggested potassium deficiency. Each year since, the trees in certain areas of the orchards have shown the same symptoms. One season (1936) a block of trees was left unsprayed to determine whether the trouble was due to injury from sprays or spraying. The leaves again showed "burned" edges, although apple scab was so severe in that year that diagnosis was made difficult. It should be added, however, that there is no evidence that the scorching of the foliage has particularly affected the growth or yield of the trees; neither has there been any significant increase in yield as a result of the fertilizer treatments.

OBSERVATIONS IN ORCHARD J

The orchard in which the fertilizer treatments were begun in 1928 is known as orchard J and consists of the varieties Baldwin and Stayman Winesap. Planted in 1922, it was cultivated for seven years and then put down to blue-grass sod. There has been an occasional light discing along the tree rows. While this orchard is not particularly involved in the present discussion, the treatments are here given together with a record of the downward translocation of available potassium during 10 years of treatment in order to show that potassium is "fixed" in this soil. At first the rate of application was probably too low, but later the rate was increased (Table 1). At all times the rate of nitrogen applications was in accordance with that recommended to orchardists of the state.

From Fig. 1 it will be seen that available potassium is present in any considerable amount only at a very shallow depth in the treated plats of this particular orchard. The characteristic "fixing" of potassium (4) presents a difficult mechanical problem to orchardists who wish to supply it to fruit trees. This tendency for potash to be fixed by the surface soil, above the zone in which the absorbing roots of

[1]Contribution from the Department of Horticulture, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication February 21, 1938.

[2]Assistant and Head of Department, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 445.

TABLE 1.—*Fertilizer treatment of individual trees in pounds in orchard J.*

Plat No.	Treatment	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
3. . . .	Nitrate soda	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
	Superphosphate	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
	Muriate potash	⅞	1	1⅛	1¼	1⅜	1½	3¼	2¾	2¾	3
5.	Nitrate soda	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
	Superphosphate	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
7 .	Nitrate soda	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
	Muriate of potash	⅞	1	1⅛	1¼	1⅜	1½	3¼	2¾	2¾	3
9	Untreated	—	—	—	—	—	—	—	—	—	—

trees are abundant, has been assigned as a factor responsible for the negative results often reported from potash fertilization of apple orchards.

Determinations made by a quick test (7) showed that at the end of seven years the available potassium content of the surface 2 inches of soil was "very high" and in the next 2 inches "medium" as compared with a "low" content prior to treatment. In other words, there had not been any downward translocation of available potassium below 4 inches. At the end of 10 years there had been an additional downward movement, but it must be noted that the rate of application had been approximately doubled since 1933. Potassium is now "high" to "very high" to a depth of 6 inches, but still not deep enough to reach the majority of roots.

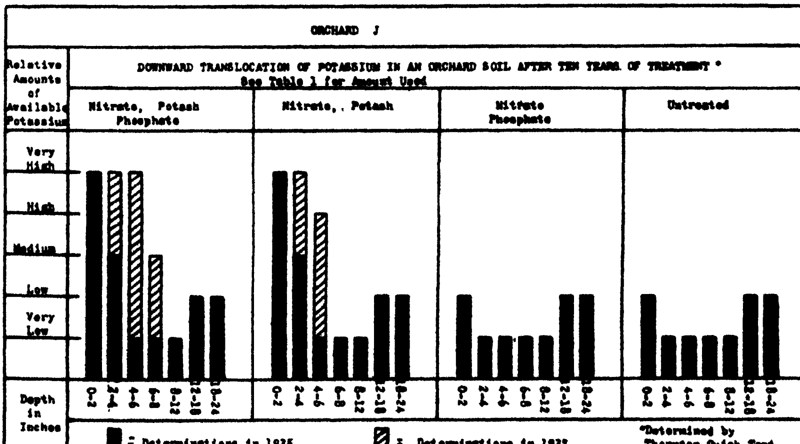

FIG. 1.

AVAILABLE POTASSIUM IN MULCHED AND CULTIVATED ORCHARDS

In contrast with the above situation a similar but more complete study has been made of mulched and cultivated orchards which have at no time received applications of potash fertilizers. These orchards are growing on a soil of the same type as Orchard J (Wooster silt loam). In this soil the trees root to a depth of 5 to 6 feet, although the majority of fibrous roots are within the first 2 to 3 feet (3).

OBSERVATIONS IN ORCHARDS A AND C

TREATMENTS

These orchards offer excellent facilities for study because of the long-time treatments of mulch and tillage. Orchard A was planted in 1893, cultivated for six years, then seeded to bluegrass and since then has been heavily mulched with straw or other litter for a total of 38 years. Wheat straw has been used most extensively. No definite record is available of the total amount of mulch added to these trees through the years, but it has been sufficient to prevent the growth of grass or weeds beneath the trees. A conservative estimate of this amount would be about 150 to 200 pounds of straw or its equivalent in other material per year per tree. Since straw contains about 1% of potassium, most of which is water-soluble, there would have been applied about 1½ to 2 pounds of potassium per tree. In the course of 30 years, since the trees had reached maturity, there has been applied a total of about 45 to 60 pounds of potassium per tree, equivalent to 2,400 to 3,200 pounds of potassium per acre of surface mulched. Incidentally, the mulch system of culture has been satisfactory as is shown by the high productivity of the orchard. The average annual yield of 15 of the better known varieties has been 15.5 bushels per tree for 26 years, or the equivalent of 620 bushels per acre at the distance the trees are planted (33 by 33 feet).

Orchard C was planted in 1915 and divided into two equal blocks. One block has been continuously cultivated with cover crops of soybeans for the summer and rye for the winter. Some years oats and sudan grass have been used. The other block was planted in sod and the mulch system was begun at once. The growth and yield of the trees under both systems of culture have been above average for this region, although recently the mulch has given somewhat superior results (3).

METHOD AND POSITION OF SAMPLING

Samples were taken by means of a soil tube at 8-inch levels to a depth of 48 inches. Whenever large roots or stones were encountered the soil tube was moved a few inches and the sampling started again. In securing the soil for samples both the mulch and sod were completely removed. Samples were first taken under the heavy mulch at the drip of the branches, then from under the sod in the interspaces between the trees at positions as comparable as possible, as far as soil character was concerned, to those from the mulched area. Samples were taken in a similar manner in the block of trees under cultivation. As a check or comparison

samples were also taken from an adjacent field in an unfertilized plat which had been in a 3-year rotation of potatoes, wheat, and clover since 1894.

METHOD OF DETERMINATION

Exploratory determinations were first made by means of a quick test (7) However, the final determinations here reported were based on the exchangeable potassium of the samples. This was done by the method outlined by Bray and Whillhite (2). In this method the exchangeable bases of the soil are replaced by the ammonium ion supplied by a neutral normal ammonium acetate solution. It is generally believed by soil chemists that the potassium displaced from a soil by treatment with a neutral normal ammonium acetate solution is as definitely related to the total available potassium in the soil as the quantity indicated by any laboratory method in use (1).

Ten grams of the air-dried soil sieved to pass 2 mm were placed in a 25-cc porcelain Gooch crucible over a neatly fitting disc of No. 1 Whatman filter paper previously moistened and pressed on the perforated bottom. The leaching solution was contained in a 250-cc volumetric flask with a stopper carrying two straight pieces of 3–4 mm glass tubing, one 6.5 and the other 7 cm long. When the filled flask was supported, inverted over the crucible containing the sample covered with a filter disc to prevent channelling of the soil and with a Pyrex beaker beneath to receive the percolate, the leaching continued without attention, as the double tube arrangement automatically admitted fresh solution to the crucible as required. The leaching process required about 8 hours.

The entire percolate was evaporated to dryness in the Pyrex beaker on a water bath and the residue of acetates ignited over an asbestos center wire gauze and Bunsen burner, slowly at first then at full heat until converted to carbonates and most of the free carbon burned off. After the addition of a slight excess of dilute HCl, the solution was again evaporated to dryness. The potassium was determined colorimetrically as described by Morris and Gerdel (5). The analytical procedure is simple, and close agreement between determinations was invariably obtained.

RESULTS

The quantitative results thus obtained indicate that available potassium was quite high from 24 to 32 inches beneath the heavy mulch in both orchards A and C (Table 2). The entire cultivated area, as well as the unfertilized field plat, was notably low in available potassium (Fig. 4). Intermediate to these extremes was the amount of available potassium present in the soil beneath the surface of the bluegrass sod near the heavily mulched trees. The soil beneath two of the trees in the mulch system (orchard C) has a content of approximately 1,000 pounds per acre of available potassium at a depth of 24 inches, while the soil beneath a tree 35 feet away in cultivation contained less than 175 pounds per acre at the same depth (Fig. 2).[4]

The same conditions exist in Orchard A but are somewhat less prominent (Fig. 3). Although limits for the amount of available potassium necessary for certain crops have not been satisfactorily determined as yet, Prince and Blair (5) state that for corn, wheat, oats,

[4]Each 8-inch horizon weighs in the neighborhood of 2 million pounds per acre of air-dry soil. Then each 0.01% K found represents 200 pounds per acre.

TABLE 2.—*Percentage of exchange potassium in orchard soil under different systems of culture.*

Tree No.	Heavy mulch, depth of sample, inches, taken 8 ft. from tree trunk						Sod, depth of sample, inches, taken 25 ft. from tree trunk					
	0–8	8–16	16–24	24–32	32–40	40–48	0–8	8–16	16–24	24–32	32–40	40–48
	Orchard A											
128	0.025	0.024	0.027	0.027	0.020	0.017	0.018	0.014	0.013	0.012	0.012	0.011
278	0.024	0.028	0.029	0.021	0.010	0.009	0.023	0.013	0.011	0.008	0.004	0.008
136	0.026	0.025	0.019	0.010	0.008	0.010	0.031	0.029	0.013	0.009	0.008	0.012
	Orchard C*											
55	0.049	0.049	0.047	0.011	0.011	0.009	0.014	0.016	0.010	0.008	0.006	0.004
4/3	0.050	0.052	0.050	0.023	0.009	0.005	—	—	—	—	—	—
	Cultivated (sampled 7 ft from tree trunk)						Cultivated (sampled 25 feet from tree trunk)					
5/2	0.017	.014	.011	.008	.004	.005	0.009	0.012	0.007	0.006	0.004	0.004
4/1	0.010	.006	.009	.009	.004	.005	—	—	—	—	—	—
3-year rotation plat 1	0.006	0.009	0.009	0.011	0.008	0.009	—	—	—	—	—	—

*Mulch was 7 feet from trees in this orchard.

clover, and alfalfa on loam soils 80 pounds or less per acre of available potassium are insufficient. One hundred and forty pounds per acre or above appear to be sufficient, other conditions being favorable. Even though these annual crops are very different in their root-

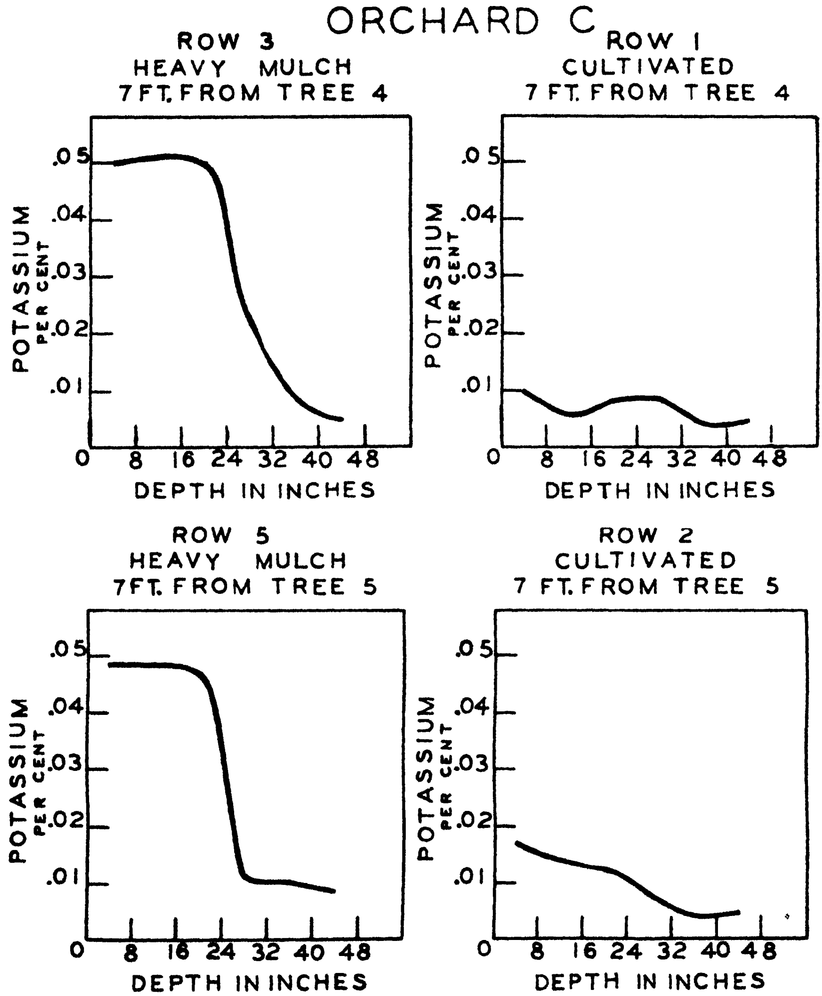

FIG. 2.

ing and growing habits than apple trees, nevertheless it would appear that the lower amounts of available potassium found in these orchards represent sufficient quantities to maintain satisfactory growth and yield.

The fact that a relatively large amount of available potassium is found at a depth of 2 to 3 feet under mulch is highly significant in the light of the characteristic fixation of potassium in the first few inches

of surface soil. Where potash fertilizers have been applied to the Wooster silt loam for a period of 10 years very little downward movement of available potassium has been observed, as indicated earlier in this paper. In no case was any potash applied to the trees under the mulch system.

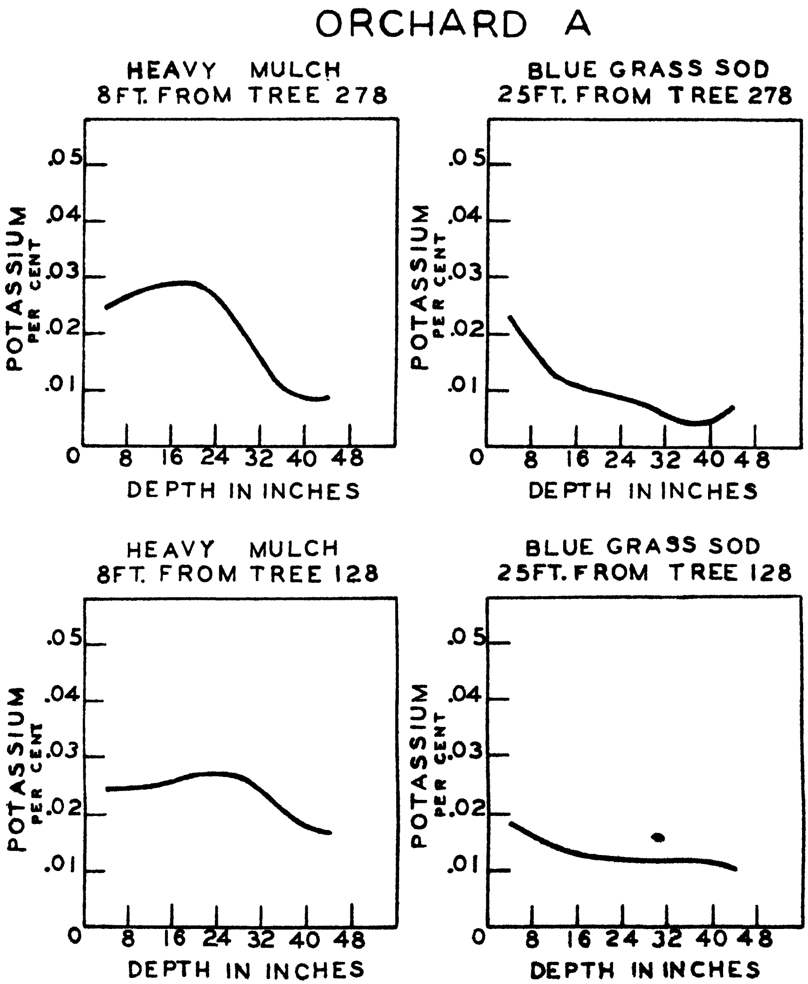

FIG. 3.

SUMMARY

Data are here presented to show the amount of available potassium under three different systems of culture, *viz.*, mulch, sod, and cultivation with cover crops, which have been maintained over a relatively long period of time on a Wooster silt loam soil. The investigations included both fertilized and unfertilized plats.

Both a quick test and a method including the quantitative determination of replaceable potassium were used. On plats under grass and clean cultivation with cover crops and treated with a potash fertilizer, it was found through "quick" tests that there had not been any appreciable downward movement of available potassium beyond a depth of 6 inches. The treatments have covered a period of 10 years during which there has been an increasing rate of potash application. At the present time (1938) potash fertilizers are applied at the rate of nearly 300 pounds per acre per year on the area under the trees.

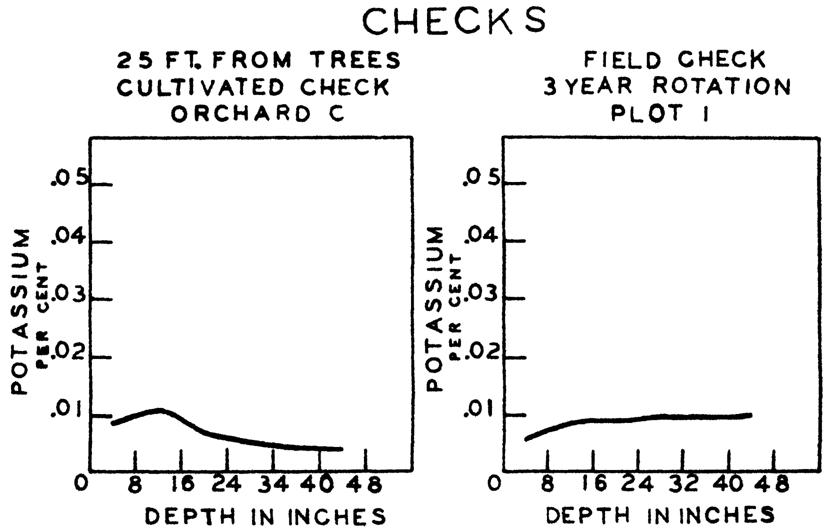

FIG. 4.

The data obtained by quantitatively determining the replaceable potassium of soil under a heavy mulch that has been maintained for a period of 22 to 38 years, upon which no potassium had been added other than that supplied by the mulch, showed that available potassium was very high to a depth of from 24 to 32 inches. This is in contrast to a lesser amount found under the adjacent bluegrass sod and a much smaller amount found under plats in cultivation with cover crops.

Available potassium was found to be "low" to "very low" in a nearby unfertilized field plat which was taken as a check on the cultivated plats.

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NOTES

A USEFUL SEED BLOWER FOR THE GRASS BREEDER

SINCE the glumes of many grasses fail to free the caryopses upon threshing, the distinction in such cases between empty florets and those containing caryopses often is difficult.

Chewing a few florets from each plant can hardly be considered a satisfactory method of estimating the plant's ability to produce seed. Crushing 100 or more florets from each plant with tweezers is too laborious and costly a method of determining the percentage of caryopses in several thousand plants.

A recent paper[1] describing the merits of a Leendertz blower for making purity determinations of commercial lots of Kentucky bluegrass seed suggested a means by which this problem may be met satisfactorily. Later correspondence with several official seed analysts[2] disclosed the fact that blowers of various types were being used in seed laboratories to assist with purity determinations. Borrowing from and adding to the ideas thus obtained, the author constructed the blower shown in Fig. 1.

Accumulating evidence indicates that climatic variations influence the percentage of florets which develop caryopses. Therefore, if a comparison of the ability of individual plants to produce seed is desired, all samples of seed to be tested should have been produced during the same set of weather conditions.

To reduce the effect of the climatic factor all grass seed harvested for caryopses determinations at Tifton, Georgia, was taken from heads possessing ripe florets and green peduncles. An effort was made to harvest all samples from any one species in the shortest time possible. By labeling tags and seed packets in advance and by keeping them in order, four men were able to collect from 1,000 to 1,500 samples per day. To facilitate separation and to make all results comparable, the seed samples for caryopses determination were oven dried at 80° C for a period of 4 or 5 days prior to making the determinations.

In the cleaning procedure from 0.5 to 1.0 gram of threshed seed from each plant is weighed and placed in the seed tubes. The empty florets are then removed by subjecting each sample to a uniform blast of air in the blower and the percentage of caryopses is determined by

[1]BROWN, E. O., and PORTER, R. H. An improved method of testing seeds of Kentucky bluegrass (*Poa pratensis* L.) Proc. Assoc. Off. Seed Anal. No. Amer., 27:44–49. 1935.

[2]E. Brown, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.; M. T. Munn, N. Y. State Agr. Exp. Station, Geneva, N. Y.; E. M. Stoddard, Conn. Agr. Exp. Station, New Haven, Conn.

weighing the sample after the empty florets have been removed. Using a chainomatic balance it is possible for one man to make 10 to 15 determinations per hour.

Last winter the percentage of caryopses in more than 5,000 samples of seed was determined with the aid of the blower described here.

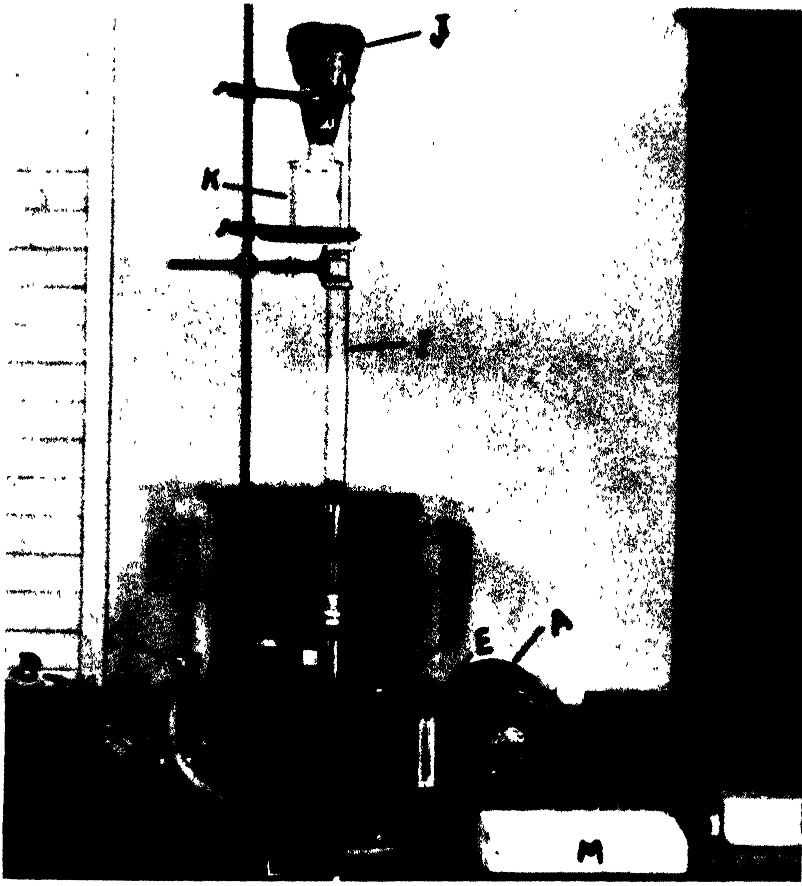

FIG. 1.—A seed blower for grass seed. The electric motor (A) pulls the blower (B) possessing adjustment (C) for regulating the air pressure. The air from the blower passes into (D), a wide-mouthed syrup pail, which acts as a pressure chamber. A mercury manometer (E) permits pressure regulation for different kinds of seeds and insures uniform blowing. Seed container (G) is a glass tube 1.5 mm. in diameter and 8 cm. long, in this case an empty photographic developer tube. One end of this tube is covered with a good grade of cotton sheeting or bolting silk held in place with a rubber band. A short piece of rubber hose (H) makes a positive connection between the seed container and the blowing tube (I), which is 24 inches long. A hole burned in one side of an erlemeyer flask (J) with an acetylene torch receives the curved end of tube (I) and permits the empty florets to enter beaker (K). A circle of large rubber tubing (L) under can (D) and the rubber cork (F) act as springs to keep seed container (G) in place and to prevent air losses. A block of wood (M) having holes numbered from 1 to 10 makes possible the running of 10 samples at one time without numbering each tube.

Seedlings from one of the *Digitaria* species produced seed ranging from 0 to 38% of florets containing caryopses. Variations in the percentage of florets containing caryopses in ***Paspalum notatum*** seedlings ranged from 10 to 98%. Such data supply a scientific basis for the elimination of plants which do not produce good seed.

A few *Digitaria* florets containing anthers (anthers are not exerted in all florets) could not be readily separated from florets containing caryopses. After the empty florets had been removed from the sample with the blower, the few florets containing anthers were removed by crushing them with a sharp scalpel.

It is doubtful if the blower will prove equally suitable for all types of grass seed. The principle of the machine, however, is good and the results obtained at Tifton would seem to warrant its use by grass breeders interested in measuring the seed setting capacity of the grasses with which they are working. Even where complete separation with the blower is not possible, it will remove a large proportion of light material and greatly reduce the hand picking necessary for a complete separation.—GLENN W. BURTON, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Tifton, Georgia.*

RESISTANCE OF CERTAIN WHEAT VARIETIES TO ATTACK BY THE WHEAT STEM MAGGOTT, *MEROMYZA AMERICANA* FITCH

A STRIKING difference in the amount of damage done to varieties of spring wheat was noted by the author on the DeKalb experiment field of the Illinois Agricultural Experiment Station on July 7, 1937. The result of the observation is here offered (Table 1) for the information of investigators who may be interested.

TABLE 1.—*Percentage of tillers of wheat showing damage by the wheat stem maggot on the DeKalb experiment field of the Illinois Agricultural Experiment Station, July 7, 1937*

Variety	Infestation, %
Thatcher	0.5
Progress	0.5
Klein-C (17)o*	9.0
Klein-C 390½*	11.0
Sturgeon	0.1
Illinois No. 1 (Mann)	0.1
Comet	0.05
Komar	0.05
Illinois 1A	1.0
Purdue 38	1.0

*Argentine varieties.

The wheat was planted May 11, 1937 (late), and the heads of undamaged tillers were still green at the time of observation. Dead heads were used as a criterion of infestation following dissection of sufficient numbers to assure us that the insect was responsible for the death in practically all cases. The differences were so easily apparent that they could not escape the most casual inspection.—J. H. BIGGER, *Illinois Natural History Survey, Urbana, Ill.*

BOOK REVIEWS

PRODUCTION OF SEED OF HERBAGE AND FORAGE LEGUMES

Edited by R. O. White. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 48 pages, illus. 1937. 5s.

TEN counties report on producing seed of forage and herbage legumes. The methods of planting legumes for seed purposes are discussed under the headings of soil types, seedbed preparation, fertilization, and seeding rates. Methods of gathering seed, periods of harvest, handling, conditioning, threshing, cleaning, and disposal of the seed is explained. This publication is of value to the plant breeder and seed-producing organizations. (R. E. B.)

COLLECTION OF NATIVE GRASS SEED IN THE GREAT PLAINS, U. S. A.

By F. J. Crider and M. M. Hoover. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 15 pages, illus. 1937. 2s.

SEVERAL rapid mechanical methods for harvesting large quantities of seed of the important species of the Great Plains area are described and photographically illustrated. Because native grasses are recognized as the basis of a general revegetation program of the Great Plains States, this publication will be beneficial to those interested in gathering seed. The types of equipment described and illustrated are flexible and would be adapted for seed collection of many pasture plants. (R. E. B.)

TECHNIC OF GRASS SEED PRODUCTION AT THE WELSH PLANT BREEDING STATION

By Gwilym Evans. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 36 pages, illus. 1937. 5s.

THE technics of propagating large quantities of seed of newly developed strains of 14 grass species are explained. Seed multiplication of new grass strains is achieved in three stages, the first from a limited number of plants selected by the grass breeder, the second on a limited field scale, and the third in terms of several fields for each strain. The first stage of multiplication is carried out at the station in glass houses. The second and third stages are carried on by growers who are paid a certain fixed sum for a 3-year period. All the multiplication operations are supervised by the station. Detailed information for establishing plantings for seed multiplication purposes and preparing the seed for disposal to farmers is given.

A great amount of pioneer work has been done by the Welsh Plant Breeding Station and this publication will be applicable to grass work in this country. (R. E. B.)

THE 1937 PROCEEDINGS OF THE SOIL SCIENCE SOCIETY OF AMERICA

Ann Arbor, Mich.: Edwards Bros. Lithoprinted from typewritten pages: cloth bound, IX+602 pages, illus. 1938. $5.

THIS volume contains the 91 papers presented at the annual meeting of the Soil Science Society of America held in Chicago November 30 to December 4, 1937. Most of the papers are given in full with a few in abstract form.

The five papers on "The Significance of Structure in Soils", presented on the general program, open the volume, with the papers presented on the several sectional programs grouped together as follows: Section I, Soil Physics, including joint sessions with Sections II and V, 15 papers; Section II, Soil Chemistry, including joint sessions with Sections I, IV, and V, 14 papers; Section III, Soil Microbiology, including a joint session with the Crops Section of the American Society of Agronomy, 18 papers; Section IV, Soil Fertility, 11 papers; Section V, Soil Genesis, Morphology, and Cartography, 19 papers; and Section VI, Soil Technology, 9 papers.

Minutes of the business meeting of the Soil Science Society and of the American Section of the International Society of Soil Science, together with other reports and announcements, make up the remainder of the volume. A table of contents and an author index are helpful supplements, while "Suggestions for the Effective Presentation of Papers" might well be perused to advantage by all who present papers on scientific programs.

Volume II maintains the same excellent mechanical standards set by Volume I and with its very substantial cloth binding presents a most creditable appearance. (J. D. L.)

AGRONOMIC AFFAIRS

NEWS ITEMS

THE NORTHEASTERN SECTION of the Society will meet jointly with Section O of the American Association for the Advancement of Science at Ottawa, Canada, June 27 to July 2. For further details on this meeting, write to Orman E. Street, Secretary-Treasurer of the Northeastern Section, Connecticut Agricultural Experiment Station, Tobacco Sub-Station, Windsor, Conn.

THE EIGHTH annual Spragg Memorial Lecture, sponsored by the Department of Farm Crops, Michigan State College, East Lansing, Mich., to commemorate the work of the late Frank A. Spragg, pioneer Michigan plant breeder, was delivered at the College on April 21 by the Honorable Henry A. Wallace, Secretary of Agriculture. The title of Mr. Wallace's address was "Corn Breeding Experience and its Probable Eventual Effect on the Technique of Livestock Breeding." The lecture is available in printed form from the Department of Farm Crops, Michigan State College.

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THE NUMBER OF LEGUME BACTERIA IN COMMERCIAL CULTURES AS RELATED TO NODULE FORMATION[1]

ALVIN W. HOFER[2]

LABORATORY studies of legume inoculants incapable of nodule formation by greenhouse tests have been carried on for several years at the New York State Agricultural Experiment Station at Geneva. Early results indicated that the inability to produce nodules might have been due to insufficient numbers of bacteria in the cultures. A study was made, therefore, for three purposes, *viz.*, (a) to determine approximately how many bacteria are required for inoculation of individual seeds, (b) to develop laboratory standards upon the basis of this information for judging whether cultures are actually deficient in numbers of nodule bacteria, and (c) to apply these standards, if possible, to the improvement of some of the brands which frequently failed to produce nodules.

Early studies of the numbers of legume bacteria necessary per seed (3,9)[3] were not successful, probably because of the inclusion in the tests of impure humus and soil cultures. In those types of inoculants which are made by mixing unsterilized material with a suspension of legume bacteria, other micro-organisms from the soil or humus may develop in great numbers upon the nutritive material provided for the legume bacteria. Recent investigation (7) has shown that peat cultures may carry great numbers of slightly fluorescent organisms, the colonies of which are almost impossible to distinguish on the culture plate from colonies of legume bacteria.

Perkins (10) stated, in regard to the first point (a), that inoculation is rather a matter of chance, since it depends upon contact between an organism and a rootlet. Nevertheless, he believed that a rather definite minimum number of nodule bacteria is required to produce maximum infection. In his investigations he found that apparently each soybean seed required 10 to 100 legume bacteria while maximum results were obtained with 25 to 50.

[1]Contribution from the Division of Bacteriology, New York State Agricultural Experiment Station, Geneva, N. Y. Approved by the Director for publication as Journal Paper No. 245, January 4, 1938. Received for publication January 5, 1938.

[2]Associate in Research.

[3]Figures in parenthesis refer to "Literature Cited", p. 459.

METHODS

In the present investigation, similar work was conducted with alfalfa and clover. Since each culture should carry one or more nodule-forming bacteria per seed, it was necessary to know how many other organisms, by plate count, would be required to insure the presence of that one organism. While this number would probably not be the same for every culture, nevertheless, if it were determined approximately, there was a chance that definite laboratory standards could be set up. These would be based upon the number of bacteria required to inoculate individual seeds and upon the number of seeds in a pound. The number of bacteria necessary by plate count could then be expressed in thousands or millions per pound of seed. After that, plate counts of commercial cultures could be compared with these figures for testing and possible revision of the standards as suggested under the second point (b) above. When standards were worked out, at least approximately, it seemed that they should prove useful in determining whether the samples that failed to produce nodules in the routine tests were actually deficient in the number of bacteria present and in securing information to assist in improving commercial cultures, as suggested under (c) above.

The first point (a) was studied by making simultaneous agar plate counts and plant counts upon commercial cultures of inoculants 2 to 8 months old. The ratio of plate count to plant count was used as the measure of how many cells among those present by plate count would be capable of forming nodules. The plate count indicated the number of bacteria present as determined by laboratory methods, while the plant count showed the number of nodule-forming organisms in each population.

In the laboratory, the counts were made by inoculation of triplicate plates from each dilution. In the case of the agar cultures, the dilutions ranged from 1:1,000 to 1:100,000,000; in the sand cultures, the dilutions covered the range from 1:100 to 1:1,000,000 per gram of sand. All counts were made upon medium 79 of Fred and Waksman (4) with 3 grams of Bacto yeast extract per liter instead of yeast water as the nitrogen source. Plates were allowed to remain in a 25° C incubator until colonies were well developed; usually about 5 days for alfalfa, clover, pea, or bean bacteria and 10 or 12 days for soybean and cowpea cultures.

The plant counts in the greenhouse were made by inoculating from each of the six upper dilutions used for plates, five (6-oz. Signet) bottles of Crone's agar (1) on the surface of which six or eight alfalfa or clover seeds had been planted. All seeds were treated in 2% chlorine solution for one-half hour, rinsed six times and dried before use. Each bottle of seeds received a 1-cc portion of inoculum, which was similar to the procedure used in making plate counts. Then, after the bottles had stood in the laboratory for 24 hours, they were kept in the greenhouse until the plants had grown and nodulation was well developed throughout the lower dilutions, a period usually of about 6 weeks.

At this time, each bottle found to have in it a nodule-forming organism, as shown by the formation of one or more nodules, was marked as plus, while each bottle without nodules was marked as minus. Since only five bottles were used per dilution, the estimates of numbers by the plant count were made by multiplying the number of positives by two and finding the most probable number of actual nodule-forming bacteria originally added by reference to mathematical tables (probability Table A, Halvorson and Ziegler, 6). Occasionally, the culture under test was much better than had been anticipated, and in such cases nodulation occurred in all of the bottles. In other cases where the culture was poor, nodulation did not occur in any of the bottles. In the majority of cases, however,

nodulation occurred in the lower dilutions and became more scattered in the higher, thus making possible a rough estimate of the number of bacteria present by use of a probability table.

Routine legume inoculant tests during the course of these investigations, and reported in Table 2, were made in sand taken from the subsoil of a field near Oaks Corners, N. Y. This was sterilized in a moist condition for 2 hours at 15 pounds steam pressure and watered with sterile distilled water and sterile Crone's solution (1).

RESULTS

BACTERIA REQUIRED PER SEED

Table 1 shows the plate counts and plant counts from a number of cultures. The ratio $\frac{\text{bacteria present by plate count}}{\text{bacteria that form nodules by plant count}}$ is quite variable for individual cultures. Since this figure represents also the minimum number of cells required by plate count if there is to be an average of one infective organism per seed, it is apparent that for different cultures this figure is not constant. Thus, although the average ratio in Table 1 would seem to be about 25 organisms by plate count for each 1 by plant count, for the purpose of setting up standards it seemed better to assume that 5 to 40 legume bacteria were necessary per seed. These figures were chosen also upon the basis of preliminary inoculant tests made for the purpose of checking the accuracy of the standards.

TABLE 1. —*Comparison of plate and plant counts on legume inoculants.*

Sample No.	Count, total numbers of bacteria in culture		Plate count ratio / Plant count ratio
	Plate method	Plant method	
	Alfalfa		
1	26	0.48	54.0
2	200	7.50	27.0
3	806	29.00	28.0
4	3,000	112.00	27.0
5	17	1.60	10.5
6	900	18.00	50.0
	Clover		
7	180	72.00	2.5
8	43	1.65	26.0
9	32	0.90	39.0
10	67	2.78	22.0
11	2,400	141.00	17.0
12	6,500	3,490.00	2.0
13	7,000	542.00	13.0
14	396	17.00	23.0

DEVELOPMENT OF LABORATORY STANDARDS

Assuming that 200,000 alfalfa seeds are present in a pound (for exact figures, see Fred, *et al.*, 5), to have 5 bacteria per seed, cultures should contain at least 1,000,000 bacteria per pound of seed they are

to inoculate; 8,000,000 per pound would probably be more certain to result in nodulation. Although these figures were derived upon the basis of alfalfa seed, they have proved helpful even with such large-seeded plants as peas. Greenhouse tests of more than 300 legume inoculants on which plate counts have been made show that, as with culture A (1932) in Table 2, the cultures with fewer than 1,000,000 bacteria per pound of seed usually fail to produce nodules. Those with more than 8,000,000 bacteria (apparently *Rhizobium*) per pound practically always induce nodulation, unless the proportion of infective

TABLE 2.—*Plate counts and nodule formation by samples of three brands of legume inoculants.*

Year	Plant group	Nodule formation*	Bacteria per pound of seed	Year	Plant group	Nodule formation*	Bacteria per pound of seed
			Culture A				
1932	Alfalfa	S	17,000,000	1937	Alfalfa	S	270,000,000
1932	Alfalfa	U	280,000	1937	Alfalfa	S	173,000,000
1932	Alfalfa	U	900,000	1937	Alfalfa	S	193,000,000
1932	Alfalfa	S	16,000,000	1937	Alfalfa	S	6,000,000
1932	Clover	S	13,000,000	1937	Alfalfa	S	193,000,000
1932	Clover	U	None found	1937	Alfalfa	S	670,000,000
1932	Clover	U	2,000,000	1937	Clover	S	20,000,000
1932	Clover	U	2,000,000	1937	Clover	S	7,000,000
1932	Clover	S	7,000,000	1937	Peas	S	31,000,000
1932	Clover	S	32,000,000	1937	Peas	S	30,000,000
1932	Clover	U	550,000	1937	Beans	S	34,000,000
				1937	Peas, beans, lima beans, lupines	S	107,000,000
				1937	Peas	S	
					Beans	S	
					Lima beans	U	
					Lupines	S	350,000,000
			Culture B				
1935	Alfalfa	U	94,000,000	1937	Alfalfa	S	260,000,000
1935	Alfalfa	U	86,000,000	1937	Alfalfa	S	6,000,000
1935	Alfalfa	U	91,000,000	1937	Alfalfa	S	103,000,000
1935	Alfalfa	U	23,000,000	1937	Alfalfa	S	58,000,000
1935	Alfalfa	U	41,000,000	1937	Alfalfa	S	53,000,000
1936	Alfalfa	P	28,000,000	1937	Alfalfa	S	257,000,000
1936	Alfalfa	P	96,000,000	1937	Alfalfa	S	401,000,000
1936	Alfalfa	P	93,000,000	1937	Alfalfa	S	46,000,000
1936	Alfalfa	P	18,000,000	1937	Alfalfa	S	43,000,000
1936	Alfalfa	P	30,000,000				
1936	Alfalfa	P	20,000,000				
			Culture C				
1935	Peas	U	8,000	1937	Peas	S	157,000,000
1935	Peas	U	37,000	1937	Peas	S	34,000,000
1935	Peas	U	830,000	1937	Peas	S	57,000,000
1935	Peas	U	12,000	1937	Peas	S	67,000,000
1935	Peas	U	110,000	1937	Peas	S	78,000,000
1935	Peas	U	64,000	1937	Peas	S	300,000,000

*S = Satisfactory in nodulation tests; P = Poor in nodulation tests; M = Unsatisfactory in nodulation tests.

cells in the culture is unusually low, a fact, which when established, is also useful. Cultures with counts between these figures are of intermediate value.

In view of these results, it seemed that there should be no difficulty in checking to find whether failure to form nodules was due to insufficient numbers of bacteria. Table 2 shows that in culture A in 1932 approximately half the samples were incapable of nodule formation, and that in every case where nodulation failed, the number of legume bacteria was distinctly below 8,000,000 per pound of seed. In every case where nodulation occurred, there were more than 8,000,000 bacteria (apparently *Rhizobium*) per pound of seed by plate count.

To follow the relationship further in an attempt to improve the situation, specific suggestions were made to the manufacturer of this brand for increasing the number of legume organisms in the containers. To accomplish these changes (a) old cultures were removed from the market; (b) labels were printed to show the samples as good for only one year instead of two, thus preventing undue deterioration due to age; (c) the size of the containers was approximately doubled; (d) contamination was avoided, and (e) the entire surface of the agar was inoculated by spraying with a heavy suspension of the root nodule bacteria. After these changes were completed, samples of this brand produced consistent nodulation of host plants and the number of colonies by the plate count increased greatly.

Another brand (B) was satisfactory except for the alfalfa samples which were consistently poor in the nodulation tests. In Table 2 (1935), it will be noted that the numbers of what were apparently root nodule bacteria were high while nodule formation was unsatisfactory. Since the organisms present were apparently root nodule bacteria (by litmus milk and veal infusion tests), the only likely explanation seemed to be that the organisms had lost their nodule-forming ability. Storage of legume bacteria in inoculants may have a definite effect upon the laboratory characteristics of some cross-inoculation groups, as will be explained later, and it is only reasonable to assume, therefore, that such storage could affect the greenhouse performance as well.

The suggestion was made to the manufacturer, therefore, that a different strain of alfalfa bacteria of greater nodule-forming ability be used in making the cultures. A substitution was made, therefore, but as will be noted from Table 2 (1936) nodule formation was poor, although the numbers of bacteria (apparently *Rhizobium*) in the cultures continued to be high. The next year (Table 2, 1937), four strains of alfalfa bacteria of known nodule-forming ability from another source were used in the manufacturing process and all the samples produced nodules.

A third investigation was made when laboratory tests indicated that the inability of brand C to produce nodules was due to the death of the bacteria after the manufacture of the cultures. In testing, the observation was made that although the water used to wash the bacteria from the bottles became extremely turbid, indicating the presence of a large number of bacteria, actually, as judged by the plate count (Table 2) the number was low. In view of these observations,

the manufacturer made a study of the problem and the next year the cultures were prepared with openings in the caps to facilitate interchange of air through a porous material in the opening. Tests of approximately 25 samples of brand C since that time have failed to show the presence of a single culture incapable of nodule formation. The improvement in greenhouse performance, as in the case of culture A, was accompanied by a marked increase in the plate count.

The plate counts from these three brands, after the above corrections, are shown in Table 2 (1937). With one exception, all of the samples of these brands tested in 1937 produced nodules on their host plants. Table 2 shows clearly that the increased capacity for nodule formation by samples of brands A and C which had been low in numbers of nodule bacteria was accompanied by a distinct increase in the number of those organisms. Brand B in which numbers had not been deficient, naturally did not show such large increases.

During the course of these laboratory investigations, a situation occurred which was the exact opposite of that obtaining with the alfalfa samples of brand B. While with brand B colony development on agar plates was abundant and nodule formation was poor, recent instances have occurred in which no colonies were present on plates, while nodulation in the greenhouse was excellent, even when only 1/10 of the usual amount of inoculum was used.

These cases occurred with the soybean and cowpea inoculants of certain brands, and since it appeared that changes in the physiology of the bacteria had rendered them unable to grow upon the yeast-extract, mannitol agar frequently used for their cultivation, an attempt was made to devise a better medium, one which, if possible, could be prepared from pure chemicals. Accordingly, all plate counts during one season were made by using four media simultaneously. After a test of five or ten cultures, colonies were counted and new media were prepared upon the basis of the information thus secured. Best results were obtained with media containing l-aspartic acid, a growth-promoting substance for butyl alcohol producing bacteria (11); asparagin, useful in cultivation of typhoid bacteria (8); or sodium asparaginate, commonly used with soil bacteria (2). The first and the last of these have been studied most, and some of the counts obtained with the media in which one or the other occur are shown in Table 3.

It is evident from this table that the number of colonies of alfalfa, clover, pea, or bean bacteria is not improved greatly or consistently by use of these nitrogen sources. In the case of some of the soybean and cowpea cultures, however, the growth of the bacteria was entirely dependent upon the use of asparagin derivatives in place of yeast extract. It is expected that further work for development of a synthetic medium for *Rhizobium* will be carried on later.

DISCUSSION

The above investigations have shown something of the effect of the density of the legume bacterial population in an inoculant upon its capacity for nodule formation. It is apparent from Table 2 (A, B,

TABLE 3.—*Plate counts, yeast-extract agar vs. sodium asparaginate or l-aspartic acid agar.*

Type of inoculant	Plant group	Bacteria per pound of seed	
		Yeast-extract agar	Asparaginate or aspartic acid agar
Agar	Alfalfa	**180,000,000***	131,000,000
Agar	Alfalfa	**270,000,000**	232,000,000
Agar	Alfalfa	200,000,000	**219,000,000**
Agar	Alfalfa	**79,000,000**	72,000,000
Agar	Alfalfa	150,000,000	**240,000,000**
Agar	Alfalfa	200,000,000	**246,000,000**
Agar	Clover	73,000,000	**93,000,000**
Agar	Clover	580,000,000	**638,000,000**
Agar	Clover	470,000,000	**880,000,000**
Agar	Clover	1,100,000	**1,600,000**
Agar	Clover	40,000,000	**55,000,000**
Agar	Clover	220,000,000	**272,000,000**
Sand	Clover	50,000,000	**69,000,000**
Sand	Clover	134,000,000	**166,000,000**
Sand	Clover	**146,000,000**	136,000,000
Agar	Peas	**200,000,000**	195,000,000
Agar	Peas	**60,000,000**	50,000,000
Agar	Peas	130,000,000	**151,000,000**
Sand	Peas	**4,000,000**	3,700,000
Sand	Peas	480,000	**610,000**
Sand	Peas	**6,400,000**	3,400,000
Agar	Soybeans	**270,000,000**	24,000,000
Agar	Soybeans	None found	**140,000,000**
Agar	Soybeans	None found	**220,000,000**
Agar	Soybeans	None found	**180,000,000**
Sand	Soybeans	23,500,000	**161,000,000**
Sand	Soybeans	21,000,000	**29,000,000**
Sand	Soybeans	13,000,000	**18,000,000**
Agar	Cowpeas	None found	**243,000,000**
Agar	Cowpeas	None found	**234,000,000**

*The higher count in each case is indicated in bold faced type.

and C, 1937) that while in the more recent tests nodule formation was consistently good, the number of the bacteria in samples of legume inoculants was still variable. Table 2 shows that the number of legume bacteria in alfalfa cultures from brand A varied from 6 millions per pound of seed to 670 millions per pound with the most constant figure at about 200 millions. In the alfalfa series of culture B, upon the same basis, counts varied from 6 millions to 401 millions with the most constant figure near 50 millions. In the other cross-inoculation groups, the figures were about the same, as shown by cultures A and C.

At present, very few cultures made by the better companies contain so few bacteria that this factor can be suspected of causing failure in the nodulation tests. Nevertheless, it is possible that the 2 to 3% of cultures incapable of nodule formation which came from the more reliable factories in recent years were poor because an insufficient number of legume bacteria were present. Certainly, some of the low-count samples in Table 2 (1937) were in the range where the formation of nodules might be expected to be uncertain.

Since the variation in these products is so extreme, the question arises whether commercial cultures can be obtained that are more constant in the number of root nodule bacteria present. Apparently the only method now available for reducing the extreme variation is by mixing the contents of several samples. When fields of sufficient size are being seeded, the water used to wash the cultures from the containers might be mixed and the proper amounts per lot of seed withdrawn from the mixture.

The results of this investigation show that variation in numbers is a factor which must be considered in the manufacture and use of legume inoculants. Besides the extreme variation in numbers of bacteria in containers designed for use with uniform amounts of seed, there are cases where the proportion of bacteria actually capable of forming nodules upon their host plants vary widely from the usual range. Furthermore, it is known (5, 12, 13, 14) that the nitrogen-fixing capacity of different strains, even in the same cross-inoculation group, may vary widely.

In view of the above findings, it is apparent that for reasonably consistent nodule formation, cultures should carry on the average 80,000,000 to 200,000,000 bacteria per pound of seed they are to inoculate. In this way, the proportion of samples containing a sufficient number of bacteria for production of nodules will probably be high. These bacteria should have among them a large enough proportion of cells actually capable of nodule formation to cause infection to the desired extent. In addition, according to the results of the above investigations (5, 12, 13, 14), the strains used in the manufacture of the cultures should have the ability to fix relatively large amounts of atmospheric nitrogen in symbiosis with the plants for which they are intended.

CONCLUSIONS

1. A study was made (a) to determine the number of individual legume bacteria necessary for the inoculation of individual seeds of alfalfa and clover, (b) to develop laboratory standards for judging whether cultures were deficient in numbers of nodule bacteria, and (c) to use these standards for improving the cultures that failed to produce nodules.

2. Comparisons of plate counts and plant counts of alfalfa and clover inoculants indicate that roughly between 5 and 40 bacterial cells are required for the inoculation of an individual seed.

3. Data from tests of more than 300 inoculants show that laboratory standards based upon these figures correlate quite well with results of nodulation tests except in cases where the bacteria have to a large extent lost their infective ability, or where the medium is not suited to the organisms which are being counted.

4. Cultures that carry fewer than 1,000,000 bacteria per pound of seed usually fail to produce nodules in the greenhouse; those which carry 8,000,000 or more (apparently legume bacteria) usually form nodules upon their host plants. Cultures with counts between these figures are of intermediate value, but usually form nodules.

5. Some of the brands which failed to produce nodules were studied to find whether they were deficient in the number of legume bacteria present. It was found that one (A) was consistently low in numbers of bacteria, a second (B) contained alfalfa organisms that had lost the ability to form nodules, and a third (C) had apparently developed a large number of organisms which had died later.

6. The manufacturers corrected these situations (a) by increasing the number of legume bacteria per culture, (b) by the use of strains of greater nodule-forming ability, and (c) by the use of a stopper which allows aeration of the culture and thus permits the bacteria to live.

7. Lack of growth in the laboratory by soybean and cowpea bacteria from legume inoculants capable of nodule formation was corrected when sodium asparaginate or l-aspartic acid was used as the nitrogen source in place of yeast extract.

8. The number of legume bacteria in the individual packages of a series of inoculants varies enormously.

9. Apparently the only way in which this extreme variation can be controlled at present is for the user to mix the wash water from several packages of inoculants and then to withdraw proportionate amounts for inoculation of definite amounts of seed.

10 For best performance inoculants should probably carry 80,000,000 to 200,000,000 nodule bacteria per pound of seed the culture is intended to inoculate. Such organisms should be high in nodule-forming ability and in capacity to fix atmospheric nitrogen in symbiosis with the host plant.

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CROP PRODUCTION ON LAND BADLY DAMAGED BY WIND EROSION IN THE GREAT PLAINS[1]

CHARLES J. WHITFIELD[2]

DURING the past five years the effects of wind action on soils in the Great Plains have been brought to the attention of the people of this country by the yearly occurrence of numerous dust storms. At Dalhart, Dallam County, Texas, which is near the heart of the "Dust Bowl", there were 61 dust storms reported in 1935, 45 in 1936, and 60 in 1937. Another striking manifestation of the work of wind action in this region is the sand dune area which has developed in recent years as a result of cultivation, grazing, and drouth on lands where previously no dunes were present. At least 12 such sites are to be found in Dallam County alone, and numerous others occur in Texas, Colorado, Kansas, Nebraska, Wyoming, North Dakota, and South Dakota.

A sand dune area consists of two distinct parts, namely, the hard eroded land from which soil materials have been removed and the dunes proper. The former lies to the west and southwest, as well as between the dunes, and has been found eroded to depths of as much as 4 feet. The dunes themselves are large piles of sand ranging from 50 to 770 yards long, 30 to 50 yards wide, and from 2 to 30 feet in height.

Early in 1936 the Soil Conservation Service established a project to see whether such dune areas could be stabilized and whether they could be returned to utilization if this were done. Within a short time it was found that a great deal of sand movement was occurring on these areas, and that the size and height of the dunes, rate of wind movement, and condition of the soil material greatly influenced the amount of blowing. One small dune was found to have moved 155 feet during a 10-week period, while a much larger one advanced only 37 feet in 52 weeks.

DUNE STABILIZATION

As is well known, a vegetative cover is the best means of preventing soil material from moving. To stabilize effectively the sand by the establishment of a cover, it first became necessary to decrease the height of the dunes to a point where they could be successfully planted. By utilizing the wind to blow away the very sand that it had built into dunes, it proved possible to lower them to the proper level. Three principal means were employed for this purpose, *viz.*, wind intensifiers, dragpole, and tractor and road grader.

Wind intensifiers of several types proved very efficient in moving sand, large gaps being dug out of the dune by the action of the wind and the sand carried out beyond the crest (Fig. 1). The use of such means to lower dunes did not prove to be practical, however, because

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Amarillo, Texas. Received for publication January 31, 1938.
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too much manual labor was involved, both in setting up the intensifiers and in digging out those that were undermined and toppled over and became totally or partly covered by the moving sand during heavy windstorms.

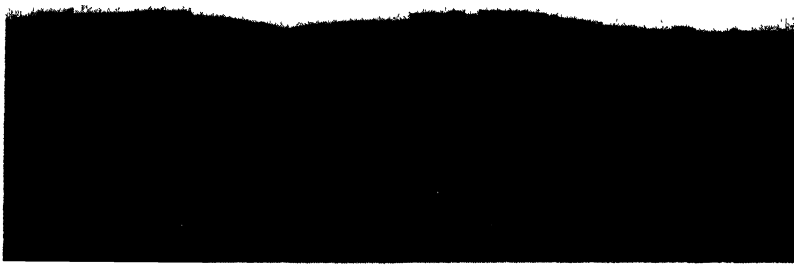

FIG. 1.—Wind intensifiers made of boards and galvanized iron and placed on top of dunes. Foreground, badly eroded area; in background is a dune 26 feet high.

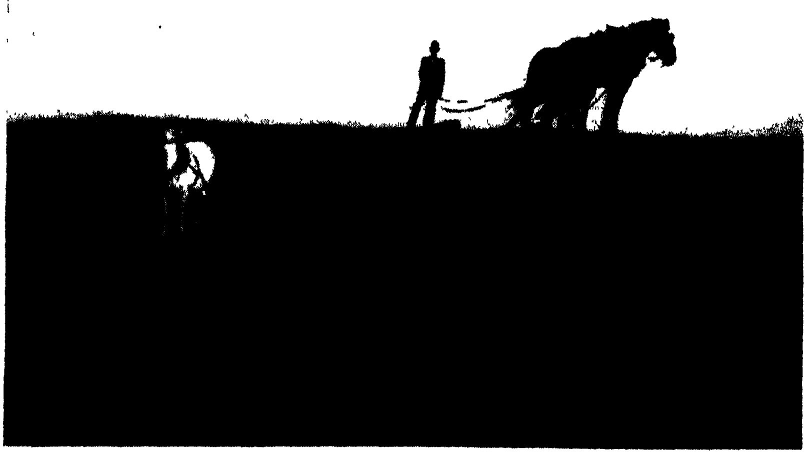

FIG. 2.—The drag-pole method showing pole and method of treatment used to break the crests of the dunes in order to facilitate sand movement. This method is more effective than others tried in utilizing wind action to lower dunes.

The drag-pole, an 8 by 8 inch pole of sufficient length to stretch from the crest of the dunes down the leeward slope to their base, was operated by hitching one or two horses to each end and dragging it along the sharp edge at right angles to the crest (Fig. 2). The drag-pole procedure is much more efficient than the wind deflector in that there is less hand labor, a greater area can be covered in a shorter time, and correspondingly larger amounts of sand can be moved. When the tractor and blade were used a wind channel was cut in the

dunes, parallel to the direction of the wind, by making one to three turns over the highest points, giving the wind a chance to move the

FIG. 3.—The tractor and grader method of cutting wind channels on one of the large dunes to accelerate lowering the dune.

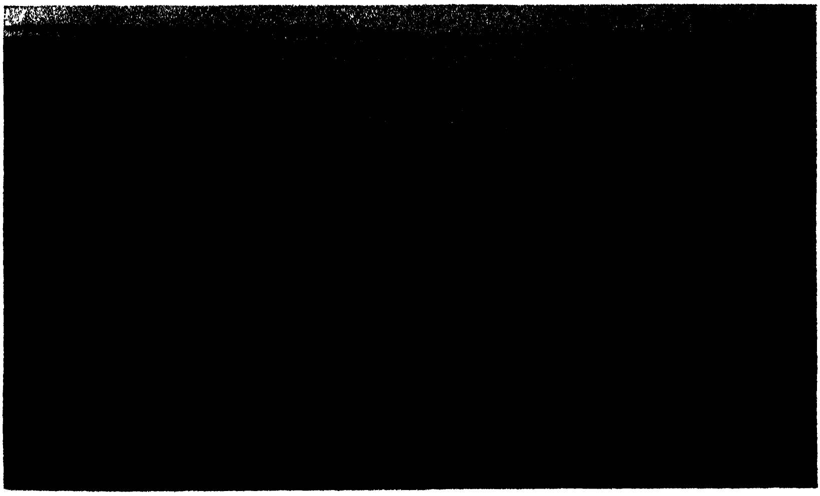

FIG. 4.—Sand caught in lister rows on the treated dune area. When these furrows fill the land will be re-listed.

sand (Fig. 3). One 20-foot dune prepared for wind-blast action by this method was lowered to 5 feet during a 6-month period, thus putting it in condition for planting.

The principal method employed to prevent the sand moving from one dune to accumulate on another was deep listing on the eroded area. This procedure prevents more sand from accumulating on the dune and also catches the material blown off the dune. Re-listing was done over much of the area, and the soil, even that which was badly eroded, was mixed with sand and other wind-blown material to such an extent that it became feasible to plant most of it (Fig. 4).

VEGETATIVE COVER

In order to determine which crop species were more adaptable to the various soil and erosion conditions existing on the treated dune area of some 400 acres, the following practice was initiated: The field was first divided into four parts, each of which was subdivided into seven smaller units, each unit being planted to a different crop. Sudan grass, black amber cane, kafir, milo, broomcorn, hegari, and millet were used. The ordinary farm procedure in general practice throughout the region was used on the research area. The crops were listed and drilled, then planted the last part of May and early June. The amount of precipitation received on the sand dune area was above normal for May only and below average for the months of June through October, or nearly the entire growing season.

A comparison of the various species planted showed that broomcorn developed a better stand and produced a more vigorous growth over the entire area, individual plants ranging from a height of 18 inches in the poorer subsoils to 8 feet in the better soils. Sudan grass was second in importance, with black amber cane, hegari, and kafir corn next. Furthermore, observations indicate that broomcorn and sudan are more resistant to wind action than the other species These two crops thus acquire greater significance in areas subject to severe wind erosion.

Plant response was measured in relation to soil and subsoil type. On areas where minor accumulations had occurred the best growth of all crops was secured. It was interesting to note that development was better here than on cultivated areas of virgin soils upon which the protective grass cover had been practically destroyed by wind blown materials. Fair to good stands developed on subsoils that had not been too deeply eroded wherever drifting sand had been caught in the furrows. In listed subsoil areas where no sand had drifted in, there was either a very poor stand or no growth at all. Apparently the sandy materials aid crop growth by making water or nutrients more available.

The actual field tests indicate that these badly eroded lands can be reclaimed for agricultural use in relatively short periods of time.

EFFECTIVENESS OF SPRAYING WITH FERTILIZERS FOR CONTROL OF WEEDS ON ARABLE LAND[1]

B. N. SINGH AND K. DAS[2]

IN a previous communication (5),[3] a detailed study was made of the effectiveness of cultural treatments, such as varying the rate of seeding and the use of farmyard manure, on the control of weeds. In this paper are presented the results of experimentation on the relative efficiency of spraying with different fertilizer solutions in the control of annual weeds in cereal crops.

As a means of effective weed control, the value of fertilizers has been well recognized in recent years. Among the different fertilizers ammonium sulfate, sodium nitrate, calcium cyanamide, kainit, and a few others have received prominence in the direct suppression and control of annual weeds in cereal crops and grasslands.

The use of ammonium sulfate and of sodium nitrate applied in solution thus far appears to be limited to a few species only. Besides this limitation, opinion differs regarding the dosage and the degree of control obtained by each. Broadcasting under favorable conditions with calcium cyanamide or finely powdered kainit has given encouraging results with broad-leaved weed species. Experiments have further indicated that when mixed salts, such as calcium cyanamide and sylvanite or kainit are broadcast, an equally effective suppression accompanied by a higher yield of the crop is obtained. No knowledge exists, however, of the behavior of fertilizers in suppressing the weeds of arable land in the tropics where the problem is especially acute due to various favorable environmental and edaphic factors, *viz.*, high moisture content and high light intensity, which apparently favor a vigorous growth not only of the crops but also of the weeds.

Moreover, certain weeds seem to have a close correlation with the fertilizers according to their nutrient requirements. There is a general tendency of the nitrogenous manures to encourage weed growth while minerals seem to behave otherwise. Studying the influence of manuring on the weed flora of arable land, Warington (8), on the other hand, has observed that the cumulative effect of long-continued manuring is of secondary importance except in certain instances of serious deficiency in the soil, such as lack of nitrogen or exhaustion of the minerals induced by prolonged application of ammonium salts only.

It thus appears that the influence of fertilizers in suppressing various species of weeds is by no means clear. A quantitative study of weed control by different fertilizers sprayed singly or in different combinations along with a study of their nutrient effect on the yield of the crop—the subject of the present study—should thus be of immense value. During the course of the present experiments, the

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[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication February 11, 1938.

[2]Director and assistant, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 473.

action of the fertilizers has been mainly judged by the killing effect on the growing tissue of the plant species resulting from the condition of plasmolysis set up in the plant cells by the greater osmotic concentration of the fertilizer solution. The difference in the growth habit, unequal age, and morphological adaptation of the two is taken advantage of in determining the relative liability to injury from a fertilizer solution. In the event of the injury not having proceeded far enough to kill the weeds, estimation is made of the extent to which the growth of the weed is checked and the extent to which the crop, receiving an additional fillip from the plant food thus supplied, keeps the weeds under suppression by reason of its increased growth.

METHOD OF EXPERIMENTATION

Altogether eight treatments, including the control (Table 1), were selected to test their relative effectiveness in the suppression of annual weeds abounding in wheat fields. The fertilizer treatments may conveniently be arranged in three main groups as follows:

A. Single fertilizers:
  1. Ammonium sulfate
  2. Sodium nitrate
  3. Potassium sulfate
  4. Superphosphate

B. Combination of two fertilizers:
  1. Ammonium sulfate + potassium sulfate
  2. Ammonium sulfate + superphosphate

C. Combination of three fertilizers:
  1. Ammonium sulfate + superphosphate + potassium sulfate

The treatments have been so selected that information may also be obtained as regards the nutritional response of the crop to spraying with fertilizer solutions containing one or a combination of two or of all three important plant food elements. In the mixed sprays ammonium sulfate has been a constant ingredient because of its apparent value in the control of weeds and in giving a fillip to the growth of the crop.

Each treatment was replicated five times in randomized plats of 1/50 acre arranged in five blocks in a field with a history of uniform crop production. The wheat seed (Pusa 4) was well cleaned so that no weed seeds were introduced through that source.

Fertilizers of a known dosage (Table 1) were applied at the rate of 100 gallons per acre with a knapsack sprayer. The spraying was done when the weeds were in the young seedling stage, i. e., when the crop was hardly more than 6 inches in height and active tillering had not yet begun. The parabolic nature of the changing density of weed flora (7) necessitates their early reduction in order to enable the crop to have a good stand.

In the course of a detailed quantitative study it was observed that among the annual weeds found in local wheat fields during the season, *Chenopodium album* and *Anagallis arvensis* have a more abundant distribution (6). This facilitated the collection and the subsequent analysis of the data where random samples had to be taken. The test of efficiency of the treatments employed has, therefore, been intentionally confined in the present paper to the data on the control of these two weed species only.

To determine both the degree of weed infestation and the control obtained by the various treatments, counts of the number of individuals of the above two weed species were made in a set of 20 random but pegged samples of 1 square foot quadrats in each plat before the spraying and three weeks after so that the partially injured plants may have sufficient time to recover.

Square quadrats were selected since in a previous study (5) such a form had been demonstrated to be more suitable than strips of the same size. A smaller unit was used, however, in these studies with a view to minimizing labor since a large number of counts had to be made. The difference between the two counts gave the degree of control obtained. The grain yield was also recorded to compare the effects of the treatments on the yield of the crop.

STATISTICAL ANALYSIS OF THE DATA[4]

Since the variance of the estimates of density (number of individuals per square foot) is discontinuous, statistical computations to compare the significance of the different treatments on the reduction in weed density have been confined to the square roots of the number of individuals in unit area (1).

The covariance method of statistical analysis has been shown in recent years to be of considerable value in correcting yields of both annual and perennial crops in successfully removing local differences by utilizing previous yield records of individual plats (2, 4). This method has further been suggested (3) to correct yield for uncontrolled inequalities arising early in an experiment and of analyzing the effects of developmental factors on yield. Analysis of covariance has also been used to determine the relation between the morphological plant character and lodging in cereals (2).

The covariance method of analysis has been resorted to in order to adjust the mean square roots of the densities after spraying (Y variable) for the other variable (X), i. e., mean square root of density before spraying, since it is to be expected that the density after spraying is closely correlated with the original density. Analysis of variance and covariance, analysis of adjusted variance of densities, and the corrected density after spraying of the two weed species are shown in Tables 2 to 5.

The residual correlation between the densities before and after spraying is significantly high (+ 0.78) in *C. album*, indicating that the two densities are closely associated. The error regression coefficient, eliminating the influence of the treatments and the soil differences, is 1.863. Taking advantage of the relation $(Y - \bar{Y}) = 1.863\ (X - \bar{X})$, the uncontrolled variations arising early in the experiment are reduced and the precision of the final results is enhanced. Utilizing the mean covariance, improvement in efficiency is also brought about by reducing the residual variance. The corrected square roots of densities of *C. album* after spraying are shown in Table 4.

In the case of the other weed species, *A. arvensis*, the residual correlation is low (+ 0.29) showing a poor association of the two densities. Error regression coefficient is also 0.2976. The use of this method has therefore not been of much help in correcting the final estimate of density (Table 4).

[4]Our thanks are due to Prof. P. C. Mahalanobis of the Statistical Laboratory, Calcutta, for the useful suggestions in the statistical analysis of the data.

RESULTS

DEGREE OF CONTROL

An examination of the data (Tables 1 to 5) on the degree of control obtained by the various treatments indicates that among the single fertilizer sprays the two nitrogenous fertilizers, ammonium sulfate and sodium nitrate, gave significantly higher control of both weed species than either potassium sulfate or superphosphate. There is no significant difference, however, in the herbicidal effect between these two nitrogenous fertilizers, both showing nearly the same degree of

TABLE 1.—*Treatments and quantities of fertilizers applied per plat and per acre and the degree of control obtained.*

Treatment No.	Treatments	Dosage		Percentage of control obtained	
		Lbs. per plat	Cwt. per acre	*C. album*	*A. arvensis*
T_1	Control	——	——	——	——
T_2	Ammonium sulfate + potassium sulfate + superphosphate	2.5+2.5+2.5	3.35	73.94	76.26
T_3	Sodium nitrate	5	2.24	55.51	66.53
T_4	Superphosphate	5	2.24	33.36	43 56
T_5	Potassium sulfate	5	2.24	41.36	42.36
T_6	Ammonium sulfate	5	2.24	56.96	65.9
T_7	Ammonium sulfate + potassium sulfate	2.5+2.5	2.24	63.53	68.14
T_8	Ammonium sulfate + superphosphate	2.5+2.5	2.24	61.74	62.9

TABLE 2.—*Analysis of variance and covariance of the square roots of densities of C. album and A. arvensis before and after spraying.*

Variance due to	D. F.	S. S. before spraying X^2	S. S. after spraying Y^2	Sum of products (covariance) XY	Correlation coefficient r	Regression coefficient b
			C. album			
Block	4	2.52	1.04	——	——	——
Treatment ..	6*	14.89	167.96	41.68	0.83	——
Error ..	24	19.09	107.52	35.57	0.78	1.863
Total (treatment + error).....	30	33.98	276.52	77.25	——	——
			A. arvensis			
Block... ...	4	4.68	1.96	——	——	——
Treatment ..	6*	0.41	84.748	4.18	0.709	——
Error.	24	9.44	15.14	2.81	0.24	0.2967
Total (treatment + error)....	30	9.85	99.89	6.99	——	——

*Degrees of freedom for treatments are 6 since one treatment (control) is not taken into consideration in this analysis.

TABLE 3.—*Analysis of variance of the adjusted square root of densities after spraying of C. album and A. arvensis.*

Variance due to	D. F.	*C. album*			*A. album*		
		Adjusted S. S.	Adjusted M. S. S.	Ratio of variance	Adjusted S. S.	Adjusted M. S. S.	Ratio of variance
reatment ..	6	58.51	3.75	5.44	80.63	13.44	21.67
rror	23	41.25	1.793	—	14.30	0.62	—
otal (treatment+error)	29	99.76	11.543	—	94.93	14.06	—

TABLE 4.—*Mean square roots of densities per 1 square foot of C. album and A. arvensis before and after spraying.*

Treatment No.	*C. album*			*A. arvensis*		
	Mean sq. root of density before spraying	Mean sq. root of density after spraying	Corrected mean sq. root of density after spraying	Mean sq. root of density before spraying	Mean sq. root of density after spraying	Corrected mean sq. root of density after spraying
T_2	5.63	2.82	3.27	3.49	1.66	1.66
T_3	6.09	4.14	3.73	3.53	2.04	2.03
T_4	5.90	4.79	4.73	3.52	2.64	2.63
T_5	5.93	4.52	4.41	3.52	2.69	2.68
T_6	5.89	3.85	3.81	3.49	1.99	1.99
T_7	5.95	3.56	3.41	3.48	1.94	1.95
T_8	5.69	3.51	3.84	3.50	2.08	2.08

control. This observation is contradictory to the generally accepted view that sodium nitrate is inferior to ammonium sulfate and its use therefore limited as an effective stimulant to enable a vigorous growth of the crop and thereby suppress the competing weeds.

Spraying with the non-nitrogenous fertilizers, such as potassium sulfate and superphosphate, gave the least control of both weed species for all the treatments. The data further indicate that the differences between the two treatments is also not significant, although with *C. album* potassium sulfate gave a higher degree of control while in the case of *A. arvensis* superphosphate appeared most efficient. (See Figs. 1 and 2.)

With both weed species, spraying with a combination of two fertilizers, ammonium sulfate and superphosphate or ammonium sulfate and potassium sulfate, did not appear to enhance very much the herbicidal efficiency of the two nitrogenous fertilizers, although the combinations did give significantly better results than either potassium sulfate or superphosphate alone. Also, there was no significant difference between these two treatments, although in general the combination of ammonium sulfate with potassium sulfate seemed to give better results than the addition of superphosphate to ammonium sulfate (Table 5).

TABLE 5.—*Significance of the adjusted mean square roots of densities after spraying.**

Treatment No.	T_3		T_4		T_5	
	C. album	*A. arvensis*	*C. album*	*A. arvensis*	*C. album*	*A. arvensis*
T_2	*	+	+	+	+	+
T_3			+	+	+	+
T_4					*	
T_5						
T_6						
T_7						

Treatment No.	T_6		T_7		T_8	
	C. album	*A. arvensis*	*C. album*	*A. arvensis*	*C. album*	*A. arvensis*
T_2	+	+	*	+	+	+
T_3	*	*	*	*	*	*
T_4	−	−			−	−
T_5	−	−	−	−	−	−
T_6			*	*	*	*
T_7					*	*

*Explanation of signs:
+denotes that the density in the vertically indicated treatment is *significantly greater* than the horizontally indicated one.
denotes the reverse, i.e., it is *significantly less*.
*denotes that the difference is *insignificant*

The most effective treatment was a combination of ammonium sulfate, superphosphate, and potassium sulfate where a consistently high degree of control was obtained for both weed species. Comparing the mean square root of densities after spraying (Table 5), it is observed that in the case of *C. album* this treatment gave significantly better result than all the other treatments except sodium nitrate and the combination of ammonium and potassium sulfates, but on the contrary, spraying with the combination of the three fertilizers gives, in the case of *A. arvensis*, significantly better result than any of the other treatments. A range of 10 to 30% increase in the degree of control over the other treatments is obtained by spraying with this mixture.

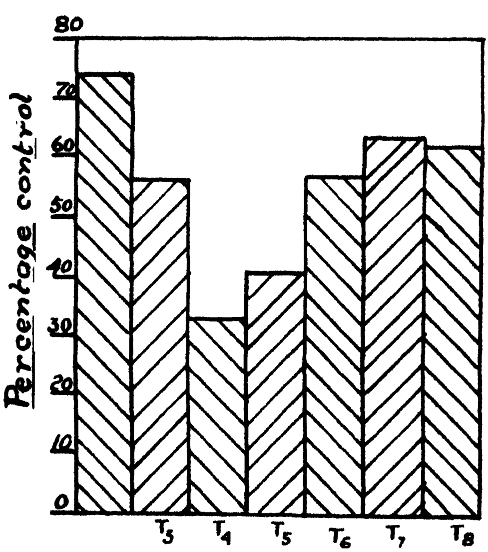

FIG. 1.—Degree of control of *C. album* obtained with different fertilizer treatments.

Excluding the combinations of sulfate of am-

monia and superphosphate or the double sulfates of ammonia and potash, a slightly higher degree of effectiveness is obtained by all the other treatments in the control of *A. arvensis* than in the case of *C. album*. Though the increase is not always consistent, the difference of such a behavior may be accounted for by the relative hardiness and morphological peculiarities of the two weed species. *C. album* besides having leaves with waxy hairs which make wetting and penetration of the solution difficult, also appears to be more resistant than *A. arvensis*, resulting therefore in a slightly higher degree of control of the latter.

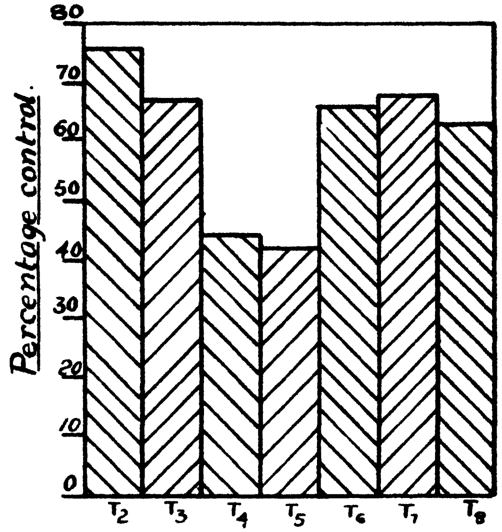

FIG. 2.—Degree of control of *A. arvensis* obtained with different fertilizer treatments.

The interaction of the factors bringing about the differential behavior of the spray solutions is not clearly defined. The unequal osmotic concentration of the different solutions, the quantity of solution adhering to the surface of the tissue for varying lengths of time, and the relative toxicity of the different ions are factors which seem to be partly responsible for the final result.

EFFECT ON YIELD

Analysis of the data on the effect of these sprays on the yield of the crop infested indicates that the layout and the experiment have been highly significant at 1% level of significance (Table 6). Examination of the data in Table 7 reveals that all the treatments gave significant increases in yield as compared to the mean yield of the control plats.

TABLE 6.—*Analysis of variance of the yield of grain.*

Variance due to	D. F.	Total S. S.	Mean S. S.	Ratio of variance
Block	4	6.02	1.505	——
Treatment	7	70.714	10.102	19.964**
Error	28	19.74	0.506	——
Total	39	96.474	12.113	——

Of all the treatments, the highest increase in yield was obtained from the mixed spray of ammonium sulfate, potassium sulfate, and superphosphate with an increase of 19.78% over the control (Fig. 3). Ammonium sulfate in combination with potassium sulfate gave the next best result. The lowest increase was obtained from potassium sulfate with only 6.82% increase. The treatments arranged in de-

TABLE 7.—*Mean yield of grain in pounds per plot for the treatments.*

Treatments	Mean yield in pounds per plat	Percentage increase from the control mean
T_1 (control)	20.22	—
T_2	24.22	19.78
T_3	22.58	11.67
T_4	21.78	7.71
T_5	21.6	6.82
T_6	23.44	15.92
T_7	23.98	18.59
T_8	23.28	15.13
Critical difference required for significance between the treatment means at P=0.01		0.90

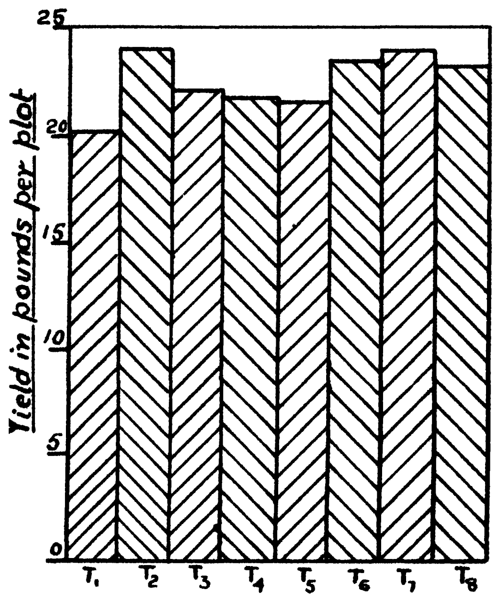

FIG. 3.—Yield of wheat in pounds per plat under different fertilizer treatments for weed control.

scending order of increase over the control were as follows: Ammonium sulfate, potassium sulfate and superphosphate; ammonium sulfate and potassium sulfate; ammonium sulfate; ammonium sulfate and superphosphate; sodium nitrate; superphosphate; and potassium sulfate.

The difference between the treatment where the highest increase in yield was obtained and any one of the treatments with ammonium sulfate alone or in combination with either potassium sulfate or superphosphate was not significant. Similarly, no significant difference was traced between ammonium sulfate alone and its use in combination with either superphosphate or potassium sulfate. No significant difference was traced between the effects of potassium sulfate and superphosphate.

It has not been possible to trace a relationship between the reduction of weed density and the increase in the yield of the crop since the latter may result from the combined effect of the reduction in intensity of weed competition and the extra nutrition added in the fertilizers. There are indications, however, that the association of weeds does not necessarily always result in a poor yield of the crop. The average increase in yield in the plats treated with the mixture of ammonium sulfate and superphosphate was 19.78% of the mean yield in the control plats, while the mean weed density of the two weed species,

in the control plats was, roughly, 3.5 and 4.5 times, respectively, of the number of individuals found in the plats sprayed with this mixture. Allowing for the proportionate share of the manurial effect in the increase in grain yield, it may be inferred that a large degree of increase cannot be attributed to the indirect effect of reduction in the density of weeds. It may also be argued, on the other hand, that the two weed species are not serious competitors and hence do not significantly disturb the nutrient level of the crop.

Observations on the relative amount of crop injury by the spray solutions indicate that the crop did not suffer very much except for a slight scorching in some cases soon after spraying. Such damage was only temporary and did not affect the final yield. Apart from the morphological peculiarities that may determine the selective effectiveness of the spray, the damage may also be counterbalanced by the relative growth rates of the two. Observations on the competitive efficiency of the weeds and the crop, which will be discussed in a later paper, show that the relative growth efficiency of the crop is generally much higher than that of the common weeds abounding in it. This physiologic potentiality of the crop carries it away beyond weed competition so that a clean field is obtained in the end.

SUMMARY AND CONCLUSION

Replicated field experiments have been carried out to determine the effectiveness of ammonium sulfate, sodium nitrate, potassium sulfate, and superphosphate sprayed singly or in different combinations in controlling annual weeds abounding in a wheat crop (Pusa 4).

The relative significance of the different treatments was judged by comparing the mean square roots of weed densities after spraying. Covariance method of statistical analysis has been applied to improve the precision of the experiment and to adjust the mean square roots of densities after spraying for the original weed density before spraying.

The results with different treatments varied between 33% and 73% control of *C. album* and 42% to 76% of *A. arvensis*.

The treatments also gave significant increases in the yield of grain as compared to the control plats. The increase for the different treatments varied from 7% to 20% of the mean value of the control plats.

The combination of ammonium sulfate, superphosphate, and potassium sulfate besides giving the best degree of control for both weed species also gave the maximum yield among all the treatments.

These observations indicate that spraying with fertilizers may be advantageously used for the combined effect of reducing the weed density in cereal crops and of increasing the yield of the grain.

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DISTRIBUTION OF SUGARS, ROOT ENCLOSED, IN THE SOIL FOLLOWING CORN AND SORGHUMS AND THEIR EFFECTS ON THE SUCCEEDING WHEAT CROP[1]

JOHN P. CONRAD[2]

STRONG competition for available plant nutrients, particularly nitrates, between the growing crop following sorghums and the soil micro-organisms living on the sugars and possible other carbonaceous residues of the dead sorghum roots was suggested (1)[3] several years ago as one of the causes of the injury of sorghums to succeeding crops. More recently, the writer has reported (5) analyses of roots of sorghums showing at maturity total sugars on the basis of dry organic matter, varying from 15 to 55%, and roots of corn (a crop causing little or no injury) ranging from less than 1 to about 4.5%. Assuming that the amounts of roots were the same for the two crops, these data give added support to the hypothesis that the injury is caused in part by the sugar residues.

After sorghums, the good growth of inoculated legumes, and the response of nonlegumes to nitrogenous fertilizers, in both nitrate and ammonium forms (2, 3) cast considerable doubt on the presence of "toxic bodies" originating from the decomposition of the sorghum residues as the cause of the sorghum injury, but they suggest rather an insufficiency of nitrogen as a major part, at least, of its cause. Two factors, sorghum plant absorption, unusually complete perhaps by virtue of the vigorous growth of the sorghums, and competitive absorption by soil micro-organisms, undoubtedly greatly stimulated by feeding on the dead sorghum plants later, may contribute to this dearth of nitrogen available to the next crop.

So far in the field it has been difficult to distinguish between these two factors as they both tend to decrease yields of succeeding nonleguminous crops. This paper presents data on the effects of the decay of the sorghum residues themselves, first by giving figures on the amount and distribution of sugars left in the soil by the sorghum crop and then by comparing the areas of high residual sugars in the soil with those of decreased crop yields.

In writing of the residual sugars left in the soil in this paper it is assumed that the sugars are enclosed within living or dead roots, and not free in the soil, as in the latter condition they would without a doubt disappear rapidly because of microbial activity.

LABORATORY TECHNIC

In determining the amount of sugar left in the soil by any crop, at least two methods of procedure are possible. In one, the roots could be separated from a

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication February 22, 1938.

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[3]Reference by figures in parenthesis is to "Literature Cited", p. 483.

weighed lot of soil, washed free of adhering soil particles, dried, weighed, and then analyzed for sugars. In the practical use of this method undoubtedly considerable losses of roots and rootlets would occur, and much sugar might be lost in the wash water as many of the sorghum roots are turgid, brittle, and easily broken, exposing the cell contents to rapid diffusion. This method might give comparable results between different varieties of sorghums and between different crops, but absolute results would probably be low because of mechanical and solution losses.

A more direct method was decided upon, namely, to determine the sugars by direct extraction of the soil. Consequently, samples of soil containing the roots of the crop in question were secured from the field (by different methods to be described later), quickly brought to the laboratory, covered with 70% ethyl alcohol, boiled for half an hour under a reflex condenser, stoppered, and stored for later analysis. The method of analysis consisted of throwing the soil and roots on a Buchner funnel and leaching each sample with about 12 successive portions (about 150 ml. each) of hot 70% ethyl alcohol. The leachings were transferred to flasks and the alcohol removed by distillation under much reduced pressure until an alcohol-free aqueous solution of the sugars was secured. This solution was cleared with neutral lead acetate and "de-leaded" with di-sodium phosphate. After diluting the cleared extract to a definite volume, an aliquot was taken for the total sugar determination which was made by the colorimetric picric acid method of Willaman and Davison (8). This method allowed fairly accurate sugar determinations to be made on small amounts of much condensed extracts from considerable quantities of soil ranging from 200 to 1,500 grams per sample.

EXPERIMENTAL RESULTS

Table 1 shows the lateral and vertical distribution with respect to the crop rows of total sugars left in the soil by sorghum and corn plants, the soil samples being taken with a soil tube (7). In every case, soil under sorghums contained more sugar than under corn. The soil under one variety of corn, Orange County Prolific, which bore no normal ears, was considerably higher in sugars than that under King Philip Hybrid corn where normal ears developed. These findings are consistent with more numerous analyses of corn and sorghum roots recently published (5). Most of the sugars are concentrated near the crowns of the plants. These findings are in line with the distribution of roots found by digging into the soil beneath these crops.

In 1935, King Philip Hybrid corn and Honey sorgo were grown for the special purposes of these and other studies. The culture of these crops was previously described more in detail (4). Much larger samples of soil were taken in 1935 than in 1934 in order to determine the amount of sugar per unit weight of soil more accurately, especially where there were smaller amounts present. It will be observed, as shown in Table 1, that again the Honey sorgo had a much larger concentration of sugar beneath it than had the King Philip Hybrid corn. Under the sorgo there was an indication of an increase in sugars from the second to the fourth foot that did not occur with the Indian corn. No adequate explanation for this is offered, except that there might be a chance increase in other organic compounds in the soil which would affect the picric acid and cause its reduction. The amounts

involved, however, are probably not high enough, even if they were sugars, to cause any appreciable effect on subsequent plant growth.

TABLE 1.—*Lateral and vertical distribution of total sugars as sucrose in parts per million of dry soil in relation to the crowns of the respective crop rows.*

1934 samples:*						
Sorghum varieties	Dwarf Yellow Milo			Dwarf Yellow Milo		
Spacing between rows	6 in.			36 in.		
Lat. dist., in.†	0	1½	3	0	9	18
Depth, 1st foot	259	29.1	10.8	278	17.6	1.5
Depth, 2nd foot	5.7	——	6.2	1.7	——	1.8
Varieties, 36 in. spacing	Honey Sorgo			White Durra		
Lat. dist., in.†	0	9	18	0	9	18
Depth, 1st foot	232	15.0	11.8	650	14.2	14.5
Corn varieties	King Philip Hybrid			Orange County Prolific		
Condition (36-in. spacing)	Normal ears			No normal ears		
Lat. dist., in.†	0	9	18	0	9	18
Depth, 1st foot	2.3	2.4	2.1	22.3	5.5	4.9
1935 samples:*						
Crop (42-in. spacing)	King Philip Hybrid			Honey Sorgo		
Condition of seed	Nearly mature			Milk stage		
Lat. dist., in.†	0	11	22	0	11	22
Depth, 1st foot	3.2	2.5	—‡	443	5.6	4.4
2nd foot	1.7	2.7	—‡	1.5	2.7	1.5
3rd foot	1.3			3.4		
4th foot	1.8			15.5		

*Samples were taken with a soil tube (7).
†Lateral distance from center of row.
‡Sample lost.

It was realized that the analyses in Table 1 might be low as representing conditions supposedly being sampled. During the process of sampling with the soil tube the shearing of the roots by the tube might cause some squeezing out of the plant sap from the roots. Losses from this factor are considered to be rather low, however. Another possible reason for low results would be the unconscious effort of the operator to secure average conditions and therefore his reaction would be to avoid sampling down through the crowns of the plants in securing the cores for compositing. It is thought that if these results are low this factor would be the most important one involved. Again, in the extraction of the sugars with alcohol, because of the roots being more or less whole, extraction might be incomplete. In studies for Tables 2 and 3, the roots, after the usual extraction, were mechanically separated from the soil as completely as possible and subjected to the usual grinding and further extraction. In the samples in which the greatest quantities of roots occurred, incomplete extraction was shown, but the sugars thus recovered amounted to only about 10% at the most of the sugars already extracted.

In connection with the data reported in Table 2, the soil was carefully spaded away to a depth of 1 foot from an upright prism of soil,

6 inches wide (3 inches on each side of a sorgo plant) extending at right angles to and across the row. A wooden frame was put over this prism in such a way that it could be slid back and forth, closer to or further from, the crop row. By using the wooden frame as a guide, the prism was further prepared for sampling by shearing away with a spade practically all that remained on one side of the row. Each soil sample, as a vertical spade slice to a depth of 1 foot, was placed in a 2-liter Erlenmeyer flask and brought to the laboratory for boiling and analysis. Subsequently, and in succession, slices of soil 6 inches long, 12 inches deep, and approximately 1 inch wide, were taken in order from the row center, out towards the center of the space between rows, across another crop row which bordered on a fallow strip, and into the fallow to a distance of approximately 60 inches. As shown in Table 2, this last sample gave a reading of 6.3 p. p. m. total sugars

TABLE 2.—*Lateral distribution of total sugar as sucrose in parts per million (p.p.m.) of dry soil in the surface foot under mature Honey sorgo as found in a series of vertical soil prisms at various lateral distances from the center of the inner crop row.*

Lat. dist., in.*	-0.5	0.5	1.5	2.5	5	9	14	22	26
Sugars, p.p.m.	4,750†	3,850†	135	292	5.9	7.5	9.9	7.6	26.8
Lat. dist., in.*	30	36	38.5	40	41.25	46	53	102‡	
Sugars, p.p.m.	25.0	13.3	158	374	3,000	290	20.8	6.3	

*Lateral distance east of inner row center Center of outer row at 42.0 inches
†Includes remains of 2½ inch stubble
‡Sixty inches into fallow; therefore expected to contain no or but few roots.

as sucrose. This probably represented not sugars alone but other organic materials in the soil as well and could be considered as a control or blank on the field soil for the methods used. Any considerable amounts above this figure then would represent sugars actually present in the roots within each sample of the soil. Considering that the outer row adjoining the fallow is at "the lateral distance of 42 inches" in Table 2, it is evident that the sugars in amounts greater than 100 p.p.m. are within a relatively few inches on either side of the row centers and do not extend very far into the spaces between rows. In Fig. 1 A the amounts of sugars as ordinates are plotted logarithmically. The differences in actual sugar percentages are thus very much minimized graphically.

After investigating the soil profile vertically exposed in securing the samples for Table 2, it seemed desirable to get some idea of the vertical distribution of total sugars within the soil. Consequently, a series of 1-inch horizontal soil layers in a column of soil (containing one sorgo plant) 6 inches lengthwise of the row and 4 inches on either side of it, were secured. All of the soil from the surface to 11 inches deep in this column was secured in these successive samples, which were later analyzed, the results being reported in Table 3, and represented graphically in Fig. 1 D, where the amounts of sugars as sucrose are again shown logarithmically.

TABLE 3.—*Vertical distribution of total sugars as sucrose in p.p.m. of dry soil under mature Honey sorgo as found in consecutive 1-inch depths in a column of soil 6 inches lengthwise of the row and 4 inches on each side of it.*

Depth, inches . .	1st	2nd	3rd	4th	5th
Sugars, p.p.m . .	12,710*	3,150	1,600	1,520	400

Depth, inches.......	6th	7th	8th	9th	10th	11th
Sugars, p.p.m .	20.0	37.2	89.2	14.1	7.8	8.9

*Includes about 2½ inch stubble extending above the soil surface.

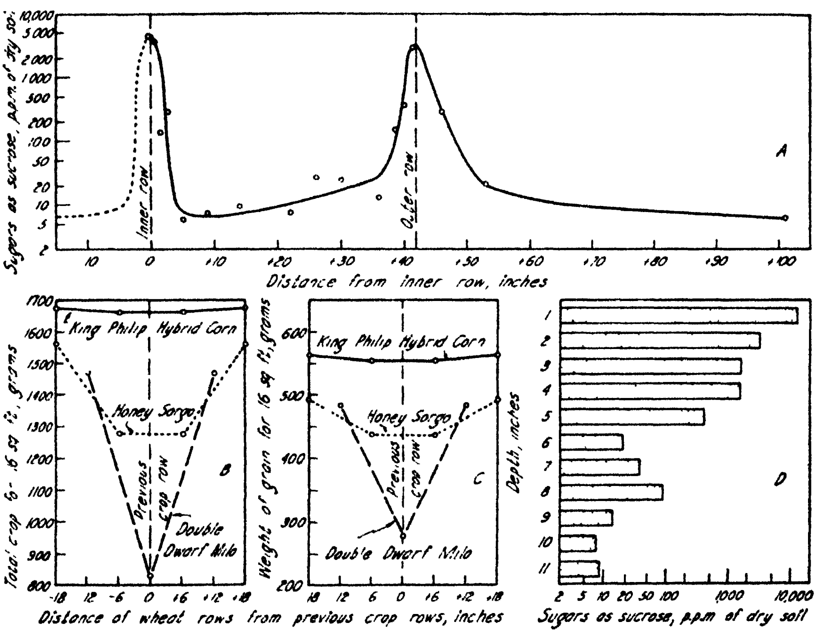

FIG. 1.—Distribution of sugars in the soil and associated injury to crop yields. A, Lateral distribution of sugars (plotted logarithmically) across two sorgo rows and into the adjoining fallow. B, Total yields of rod rows of wheat as related to distance from previous rows of corn, sorgo, and milo. C, Corresponding grain yields. D, Vertical distribution of sugars (plotted logarithmically) in a column of soil beneath a sorgo row.

From a consideration of the analyses in Table 3 alone, it might be assumed that there was considerable variation due to sampling errors. In other words, the 4th inch depth might have been considered to contain less than it did. Again, the 7th and 8th inch depths showed considerably more sugar than the 6th inch depth. It is believed, however, that additional sampling would not materially change this order. At about 4 inches in depth the bottom of the mulch occurred. Here the roots would have encountered considerably greater resistance to penetration. In an examination of sorghum roots in the row it is often possible to pull on one plant and partially pull up the roots

of the adjoining one which have entwined with the roots of the first in the furrow made by the shoe of the planter. In other words, roots developing from the crown in the later stages of the growth of the plant may move laterally several inches in this planter shoe furrow before finding a crack or other path of least resistance to move into the deeper subsoil. Again, at the 7th or 8th inch depth a plow sole occurred, representing the usual depth of plowing. This layer, somewhat compacted, undoubtedly caused the roots to accumulate above it to some extent before finding places sufficiently weak to allow easy penetration.

After the crops were harvested, shallow furrows 1 foot apart, parallel to the crop rows, were made as for planting nursery rod rows of grain and were planted to White Federation wheat on November 21, 1935. After maturity these rows were harvested in the usual way on June 20, 1936, yields obtained, and reported in Table 4. As no intervening seedbed preparation was given to the soil after harvesting of the corn and sorgo, except for the furrowing-out and as the nearest furrows varied from 3 inches to 9 inches from the crowns of the previous crop plants, the sugars in the roots, if they caused injury to the wheat plants, might be expected to affect the two rows immediately adjacent to the previous crop row. For that reason the two center rows adjacent to the previous crop row were averaged as the "affected rows" and the yields of the total crop and of the threshed grain were compared with the rows adjacent to them, one on either side. This gave a paired comparison suitable for the use of Student's method for statistical evaluation. With all of the rows as grown in these plats under conditions as described, seven comparisons for each of the crops, corn and sorgo, were secured. The average yields of the wheat rows, adjacent to the previous Honey sorgo row, were cut down as compared to the rows immediately adjacent and this reduction was statistically significant as reported in Table 4.

TABLE 4.—*The effect of previous crop rows of corn and sorghum in decreasing the yields of 16-foot rows of White Federation wheat.*

Previous crop	Number of pairs	Part of crop	Yield in grams per 16-foot row				
			Affected rows		Av. of 2 control rows*	Decrease	Student's odds (6)
			No.	Av. yield			
King Philip Hybrid corn	7	Total	2†	1,662	1,678	16	3.75
		Grain	2†	555	564.5	9.5	14.6
Honey sorgo	7	Total	2†	1,280	1,562	282	5,000
		Grain	2†	436	493	57	450
Double Dwarf Milo	8	Total	1‡	836	1,474	638	10^5
		Grain	1‡	278	484	206	3,000

*Two unaffected rows, one on either side of the one or two affected rows.
†Two affected rows adjacent to previous crop row.
‡One affected row over previous crop row.

In the lower part of this table are given data with regard to Double Dwarf milo. This crop was grown on unirrigated land in spacing trials with grain sorghum conducted by Professor George W. Hendry, and the land turned over to the writer for experimentation after harvest. To clear the land for the wheat crop, the milo plants were cut off rather shallowly below the surface with a plow and removed, resulting, undoubtedly, in the removal of a portion of the sugars. This operation, however, enabled the rows of wheat to be placed immediately over the previous crop row. As before, shallow furrows were made 1 foot apart parallel with the previous crop rows and White Federation wheat seeded in 16-foot rows on November 21, 1935. At a little distance away from these rod rows, wheat was drilled in at right angles to the previous sorghum rows. Both in this larger field and in the rod rows of wheat, near maturity, the locations of the previous milo rows were easily distinguished by the markedly reduced height of the plants. Some fertilizer trials within this adjoining field of wheat were made with nitrogenous fertilizers. Where these fertilizer plats crossed the previous milo rows, the decrease in height disappeared.

It has been observed by the writer that when sorghum plants at maturity are pulled up or plowed out there may be a considerable exudation of root sap from the end of the roots yet remaining in the soil. Each of these wet spots may attain 3 or 4 inches in diameter, undoubtedly at the expense of the sap within the roots of the plants distributed to considerable distances from the cut, i. e., upper, ends of the roots. Though no attempts to analyze this exudate have been made by the writer, this "bleeding" might cause a concentration of the sugars into the soil at or near the crowns of the previous crop. Another factor which might have been the cause of the greater injury from the milo was the heavier soil where the milo was grown as compared to that where the corn and sorgo were grown. Though no quantitative observations were made, it was felt that there was a greater amount of roots immediately at the bottom of the mulch where the Double Dwarf milo was grown than where the other two crops grew. It will be observed in Table 4 that the single rows of wheat immediately over the previous crop rows of Double Dwarf milo were reduced to almost one-half of the average of the adjacent rows. This decrease is highly significant statistically. With regard to yield of total crop the decrease of this one row is slightly greater than twice the decrease of the two rows for the Honey sorgo, but with regard to grain the decrease chargeable to milo injury is much greater than twice that chargeable to each of the two rows following the sorgo.

In Figs. 1 B and 1 C are given the distribution of yields of rod rows of wheat with respect to the previous crop rows for total crop and threshed grain, respectively. If these are compared with the concentration of sugars in p.p.m. of the dry soil as found for sorgos and shown immediately above in Fig. 1 A, it can be readily seen that the locations of the injury and of the peaks in the distribution of the sugars coincide.

DISCUSSION

A complete case for the establishment of these sugars as a cause of the injury would need some evidence as to the amount of decrease in crop yields which a given amount of sugar would cause. Such a study has been made in a preliminary way in the field and in a more complete way in the greenhouse, but the subject is so complicated that it seems desirable to publish it later. Suffice it to say that as little as 100 p.p.m. of sucrose added to soil in pots has decreased the yield of non-leguminous crops about 10% during a 7 weeks' growing period.

It is realized that in the field many factors may cause variations from these results. The length of the growing period is longer, the sucrose undoubtedly is not distributed as equally as in pots, the soil temperatures in the field are different than they are in the greenhouse, and rains may leach either the sugars or the nitrates out of the root zone at the time when they might be most effective in causing decrease or increase to the indicator crop.

The sugars in the soil, if distributed as shown in Tables 2 and 3, would be expected to influence only the wheat rows planted over or adjacent to the previous crop rows as high concentrations do not extend more than 6 inches either way from the previous crop row, as shown in Fig. 1 B. Then practically all of the injury from the sugars of the roots would be operative on the one row of wheat immediately over the milo row and on the two rows immediately adjacent to the previous sorgo row.

When these experiments were planned it was hoped that there would be a general average of crop yields following sorgo and even corn which would be lower than on the adjoining fallow. It has been our usual experience that the cultural methods used for these studies would result in such data, but in this case either the soil chosen was so fertile or the rains so persistent and leaching as to remove this difference. However, the data reported previously (4) with regard to the vertical and horizontal distribution of nitrates and moisture at this same time and location are of interest. The rainfall, of course, was sufficient during the 1935–36 season to remove moisture as a factor limiting the wheat crop. The amount of nitrates in the soil at the end of the sorghum- and corn-growing period showed little relation to the variations in yield secured. The nitrates, however, are better correlated with the yields of crops across a sorghum-fallow and corn-fallow boundary line as usually encountered in the past.

Though not demonstrated in this study possibly because of conditions of the plats chosen or the season, the amount and distribution of residual nitrates, as previously reported (4), occurring on these plats at the same time as the samples for sugars were taken, are consistent with the idea that the sorghum crop by absorbing nitrates and possibly other available nutrients in the soil reduces the supply at the disposal of the succeeding crop, thereby reducing its yield. The analytical data would indicate that such an effect might be general over the area cropped to sorghums where a stand sufficiently thick was maintained. This coincides closely with the opinion of many agronomists that considering the higher yields of sorghums it is to be ex-

pected that these crops will make heavy drafts on the soil, leaving less for the succeeding crops.

But in addition to the idea of the heavy draft by the living sorghum plants, the data contained herein clearly indicate that the sugars contained in the roots of sorghums may be so concentrated in and near the crowns of the plants as to cause soil micro-organisms, acting to decompose them, to compete with the plants of the succeeding crop, giving results harmful to the latter. Injury from this cause seems to be confined to narrow zones, each extending along an old sorghum row and not very far distant from it. Such zones of injury coincide with zones of high sugars in the soil.

SUMMARY

1. Samples taken with a soil tube from beneath corn and sorgo rows showed from 20 to over 200 times as much sugars as sucrose in the soil beneath the crowns of sorgo than under those of corn.

2. By taking larger soil samples with a spade in such a way as perhaps to be more representative of the condition sampled, than with the tube, the residual sugars expressed as sucrose were shown to occur both vertically and horizontally in highest concentrations near the crowns of the plants. Vertical slices to a depth of 1 foot, exceeding 100 p.p.m. of sugars, were not encountered over 6 inches from row centers while at the sorgo row center some were over 4,000 p.p.m. Horizontal 1-inch layers in the row and extending 4 inches on each side of it, ranged from over 12,000 p.p.m. of sugars in the first such layer to less than 10 p.p.m. in the 10th inch layer.

3. Rows of wheat parallel to the previous crop rows showed marked and statistically significant decreases adjacent to and over the row centers of sorgo and milo, while the slight decreases adjacent to previous corn rows were not significant.

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BUNT REACTION OF SOME VARIETIES OF HARD RED WINTER WHEAT[1]

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IN the fall of 1930 a coordinated cooperative improvement program for hard red winter wheat was started in the principal winter wheat producing states of the Great Plains. Because of the importance of covered smut or bunt in this area, a study of the reaction of wheats to the bunt organisms was included in the program in 1931 on a more extensive scale than studies then in progress at the state and federal experiment stations. Prior to this time many of the promising selections and hybrid lines were being tested for bunt reaction at a single station and with inoculum obtained from one locality or even from a single field. As a result, certain varieties found to be resistant in these tests were susceptible when grown commercially and subjected to other races of the bunt organism. It was apparent that, for an adequate test of varieties and promising strains, bunt reaction should be determined under a wide range of environmental conditions and by using collections of inoculum representative of various sections of the Great Plains. The purpose of this paper is to present results of bunt tests with uniform sets of winter wheat varieties and strains inoculated with the bunt organisms of a large number of collections and grown at a number of stations throughout the hard red winter wheat region.

PLAN OF THE UNIFORM NURSERIES

Fifty varieties and strains of wheat were planted in duplicate 8-foot rows each year. Most of the wheats tested were new hybrid strains found to be resistant to bunt at the stations where they were developed, but, in addition, wheats grown in the uniform plat and nursery tests and a few varieties adapted primarily to the Northwest also were included. Kharkof (C. I. 1442), Cheyenne (C. I 8885), and Quivira (C. I. 8886) were included in all tests as susceptible checks. Varieties were discontinued from the experiments as soon as it seemed that a satisfactory determination of their bunt reaction had been obtained, if they had developed an average of more than 10% bunt or proved to be undesirable agronomically.

Seed used in the tests in the first three years was treated with formaldehyde, thoroughly washed with water, and dried before applying the inoculum. In later years the seed was not treated but was taken from sources free from bunt infection.

The inoculum used for each of the nurseries was a composite of collections obtained not only in the vicinity of the station but also from fields selected at random throughout the state in which the test or

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[2]Pathologist and Agronomist, respectively. The writers express their appreciation to cooperators at the various experiment stations for their kindness in growing the nurseries.

tests were made. The most intensive bunt surveys in the Great Plains area have been made in Kansas and Montana, and the inoculum used in the nurseries at Manhattan, Kans., and Bozeman and Moccasin, Mont., included a larger number of collections than in tests conducted elsewhere. The inoculum used at Manhattan, Kans., was pure for the smooth-spored species (*Tilletia levis* Kühn). At all other stations a small percentage of *T. tritici* (Bjerk.) Wint. was present except in the Montana inoculum, where about 25% of the chlamydospores were of *T. tritici*. The definite physiologic races known to be present in the inoculum will be referred to in another section of this paper.

Nurseries were planted in some or all of the 6 years the tests have been made at Denton and Amarillo, Texas; Stillwater and Woodward, Okla.; Manhattan, Kans.; Akron and Fort Collins, Colo.; Lincoln, North Platte, and Alliance, Nebr.; St. Paul, Minn.; Moccasin and Bozeman, Mont.; Logan, Utah; and Kearneysville, W. Va.

The bunt percentages obtained were based on counts of the total number of bunted and non-bunted heads per row.

DATA OBTAINED

A summary of the data obtained at the different stations during a 6-year period is presented in Table 1. Data were not recorded from all stations every year because of environmental conditions unfavorable for bunt infection or for subsequent plant growth. The number of years individual varieties have been tested is not uniform owing to the rapid turnover in varieties. Consequently, the average percentage of infection is given in terms of percentage of Kharkof (C. I. 1442), which was grown every year at all stations, in order that the reaction of varieties may be compared directly. It is realized that this method of comparison is open to some criticism, but it gives usable and fairly comparable infection percentages. The varieties are listed in Table 1 in order of resistance as expressed in terms of the Kharkof check.

A total of 162 varieties and strains were tested for 1 to 6 years during the period from 1931 to 1937. No variety was entirely free from bunt in all tests, although 12 strains had average infections of less than 1% and 84 had less than 10%. It should be noted particularly that among the resistant varieties and selections are some that are grown commercially, including Ridit, Minturki, Oro, and Yogo. These, together with the Nebraska Turkey selections (C. I. 10016 and C. I. 10094) and Hussar are being used as parents for the development of bunt-resistant strains. It is obvious from the data that most of the resistance in hybrid lines was obtained from crosses in which Oro, Martin, or Hussar were parents.

Attention should be called to the 14 strains of Oro × Tenmarq. Twelve of these produced less bunt than did Oro and all of them much less than Tenmarq. While all of these lines were selected for resistance, it seems possible, as pointed out by Wismer (4),[3] that Tenmarq may have contributed some genetic factor or factors for resistance to produce lines more resistant than the Oro parent.

[3]Figures in parenthesis refer to "Literature Cited", p. 492.

TABLE 1.—*Summary of bunt infection of varieties and strains of winter wheat grown in the uniform winter wheat bunt nursery in the Great Plains area. 1932–37.*

Variety	C. I. No.	State No.	Percentage bunt infection in 1932, 8 stations	1933, 6 stations	1934, 10 stations	1935, 9 stations	1936, 9 stations	1937, 10 stations	"Dwarf" smut, Logan 1937, %	Weighted average* %	Percentage of Kharkof
Oro × Tenmarq	11675	Kans. sel. No. 342021	—	—	—	0.3	—	—	—	0.3	0.6
Martin × Blackhull × Blackhull	11572	Hyb. No. 29312A-3-11	—	—	0.2	0.2	0.4	0.8	0.7	0.4	0.9
Beloglina × Hussar	11583	North Platte No. 99	—	—	0.1	0.5	0.2	0.8	8.3	0.4	0.9
Turkey selection	11507	Nebr. No. 4311	—	0.3	—	—	—	—	—	0.3	0.9
Turkey selection	11095	Nebr. No. 1065	0.7	0.5	0.6	—	—	—	—	0.6	1.3
Turkey selection	11577	Nebr. No. 1081	—	—	0.7	—	—	—	—	0.7	1.3
Beloglina × Hussar	11819	North Platte No. 65	—	—	—	—	—	0.7	6.3	0.7	1.5
Turkey selection	10098	Nebr. No. 1070	1.1	0.5	0.6	—	—	—	—	0.7	1.6
Turkey selection	11506	Nebr. No. 1067	0.5	0.3	1.2	—	—	—	—	0.7	1.6
"Tiflis"	11730	F. P. I. 94476	—	—	—	—	0.6	—	—	0.6	1.7
Martin × (Tenmarq)₃	11805	Denton No. 50-33-63	—	—	—	—	—	0.8	1.5	0.8	1.8
Turkey selection	10097	Nebr. No. 1068	0.5	0.6	1.2	—	—	—	—	0.8	1.8
Kanred × Oro	11803	Denton No. 18-33-32	—	—	—	—	—	1.0	3.2	1.0	2.2
Beloglina × Hussar	11513	North Platte No. 126	—	.0	0.2	1.1	0.3	3.3	7.0	1.1	2.5
Oro × Tenmarq	11676	Kans. sel. No. 342039	—	—	—	1.3	—	—	—	1.3	2.5
Oro × Tenmarq	11807	Kans. sel. No. 343638	—	—	—	—	—	1.3	72.4	1.3	2.8
Martin × Blackhull × Blackhull	11571	Hyb. No. 29312A-2-12	—	—	0.7	2.6	—	—	—	1.6	3.0
Beloglina × Hussar	11582	North Platte No. 80	—	—	0.7	2.6	—	—	—	1.6	3.0
Wheat × Rye (Meister)	11403	———	—	—	—	1.8	2.7	.0	3.4	1.4	3.1
Beloglina × Hussar	11514	North Platte No. 89	—	0.9	1.7	—	—	—	—	1.4	3.1
Turkey selection	10016	Nebr. No. 1069	0.8	0.5	0.9	1.5	2.8	2.0	80.5	1.5	3.3
Relief	10082	———	—	—	—	—	1.6	1.2	.0	1.4	3.4
Martin × (Tenmarq)₃	11804	Denton No. 50-33-23	—	—	—	—	—	1.6	2.6	1.6	3.5
Oro × Tenmarq	11677	Kans. sel. No. 342048	—	—	—	0.3	1.3	3.2	59.4	1.7	3.8
Oro × Tenmarq	11729	Kans. sel. No. 343255	—	—	—	—	0.6	2.7	54.4	1.7	4.1
Tenmarq × Minturki	11810	Kans. sel. No. 344231	—	—	—	—	—	2.0	54.5	2.0	4.4
Sibley No. 81	10084	———	1.4	1.6	2.8	—	—	—	—	2.0	4.4
Turkey selection	11576	Nebr. No. 1082	—	—	0.7	0.9	0.5	6.1	73.8	2.1	4.5
Turkey × Bd. Minn. No. 48	8243	———	2.4	3.5	1.0	—	—	—	—	2.1	4.7
Turkey selection	10094	Nebr. No. 1063	1.9	0.6	1.5	2.9	2.1	3.0	57.6	2.1	4.7
Ridit × Nebr. No. 6	11670	Nebr. No. 1097	—	—	—	.5	1.1	4.7	61.0	2.2	4.9
Minturki × Blackhull	11671	Nebr. No. 1089	—	—	—	1.4	1.6	3.5	61.9	2.2	4.9
Minturki × (Beloglina-Buffum)	10088	Hyb. No. 19115-VI-14	2.1	1.6	2.9	—	—	—	—	2.3	5.1
Yogo	8033	———	1.7	1.0	1.1	2.3	2.3	4.8	35.5	2.3	5.1
Cooperatorka	8861	———	2.9	1.1	—	—	—	—	—	2.1	5.2
Cheyenne selection	11666	Nebr. No. 1087	—	—	—	1.3	0.5	5.2	54.5	2.4	5.3
Turkey selection	11376	———	—	2.2	1.5	2.6	3.4	—	—	2.4	5.4

Turkey selection	10096	Nebr. No. 1066	2.3	2.2	—	—	—	—	—	2.3	5.7
Fulhard×Oro	11732	Kans. sel. No 343191	—	—	—	—	1.3	3.3	77.8	2.4	5.8
Oro×Tenmarq	11806	Kans. sel. No. 342015	—	—	—	—	—	2.7	58.1	2.7	5.9
Hussar	4843	—	0.8	0.2	0.3	0.3	1.3	11.5	13.7	2.7	6.0
Ioturk	11388	—	—	0.9	2.1	2.5	3.2	4.0	6.1	2.7	6.0
Minturki×Marquis	11658	Minn. No 2615	—	—	—	1.9	3.5	—	—	2.7	6.0
Bulk hybrid selection	11743	B H. 39–65	—	—	—	—	2.2	—	—	2.2	6.0
Turkey selection	11667	Nebr. No. 1088	—	—	—	3.2	2.4	—	—	2.8	6.3
Oro×Tenmarq	11673	Kans. sel. No. 342009	—	—	—	1.1	1.8	6.2	38.7	3.1	6.9
H-44×Minhardi	11738	Minn. No. II–26–23	—	—	—	—	2.6	—	—	2.6	7.1
Tenmarq×Minturki	11580	Nebr. No. 1094	—	—	2.1	3.6	4.6	—	—	3.4	7.2
Oro×Tenmarq	11727	Kans. sel. No. 343247	—	—	—	—	2.0	4.0	29.3	3.1	7.5
Oro×Tenmarq	11674	Kans. sel. No 342018	—	—	—	0.3	0.8	6.1	65.5	3.4	7.6
Ridit	6703	—	1.7	0.8	6.2	6.6	1.5	3.0	12.4	3.5	7.8
Minturki×(Beloglina–Buffum)	11661	Nursery No. 160	—	—	—	2.9	2.6	5.0	58.3	3.6	8.0
Oro×Fulhard	11579	Nebr. No. 1083	—	—	3.3	4.3	3.9	—	—	3.8	8.0
Turkey selection	10015	Nebr No. 1062	4.5	1.4	3.6	5.1	—	—	—	3.8	8.0
Oro×Tenmarq	11731	Kans. sel. No. 343273	—	—	—	—	1.8	4.9	55.4	3.4	8.2
Kanred×Sherman	11510	No. Platte 25–26–4	3.7	2.2	5.9	—	—	—	—	4.2	9.3
Minturki×Blackhull	11817	Nebr. sel No. 321701	—	—	—	—	—	4.3	41.7	4.3	9.4
Minturki×Marquis	11501	Minn. No. 2616	—	—	3.4	6.8	—	—	—	5.0	9.5
Minturki×Marquis	11502	Minn. No 2614	—	—	2.8	6.4	4.7	—	—	4.6	9.7
Turkey×Minturki	11662	B.H. 6–1	—	—	—	3.8	4.9	—	—	4.4	9.8
Turkey selection	10100	Colo. No. 159	4.9	2.2	5.7	—	—	—	—	4.6	10.2
Oro×Fulhard	11733	Nebr. sel. No. 23766	—	—	—	—	1.9	6.4	57.1	4.3	10.4
Oro×Tenmarq	11672	Kans. sel. No. 342003	—	—	—	2.5	2.6	8.7	63.9	4.7	10.4
Oro×Tenmarq	11728	Kans. sel No. 343249	—	—	—	—	2.2	6.7	39.9	4.6	11.1
Oro	8220	—	4.7	5.3	5.1	3.0	3.3	8.9	52.2	5.1	11.3
Beloglina selection	10013	North Platte No 15	5.7	3.1	—	—	—	—	—	4.6	11.5
Oro×Tenmarq	11808	Kans. sel. No. 345046	—	—	—	—	—	5.4	49.4	5.4	11.8
Sherman×Kanred	11820	Nebr. sel No. 31B263	—	—	—	—	—	5.4	54.9	5.4	11.8
Beloglina×Minturki	11515	North Platte No 379	—	3.8	4.0	9.1	—	—	—	5.8	12.2
Beloglina×Hussar	11664	North Platte No 93	—	—	—	6.5	—	—	—	6.5	12.3
Rio	10061	—	—	3.8	6.6	—	—	—	—	5.6	12.5
Bulk hybrid selection	11744	B. H. 32–33	—	—	—	—	1.3	8.9	72.3	5.3	12.8
Kruse	11524	—	—	4.2	—	—	—	—	—	4.2	13.1
Minturki	6155	—	5.7	0.9	3.8	16.0	2.0	7.7	52.2	6.3	14.0
Beloglina×Minturki	11588	North Platte No. 353	—	—	3.2	12.6	—	—	—	7.7	14.6
Beloglina×Hussar	11663	North Platte No. 82	—	—	—	7.8	—	—	—	7.8	14.7
Minturki×Marquis	11659	Minn No. 2618	—	—	—	7.9	—	—	—	7.9	14.9
Oro×Tenmarq	11736	Nebr. sel. No. 23625	—	—	—	—	5.6	—	—	5.6	15.4
Quivira×(Fulhard–Oro)	11811	Kans sel No. 354152	—	—	—	—	—	7.1	60.2	7.1	15.5
Yogo selection	11678	Akron No. 10	—	—	—	9.6	—	—	—	9.6	18.2
Minturki×Turkey	11500	Wisc. No. 81.26	—	—	6.9	12.5	—	—	—	9.6	18.3
Tenmarq×Minturki	11809	Kans. sel. No. 343224	—	—	—	—	—	9.5	68.7	9.5	20.8
Turkey selection	11570	Woodward No 32R63	—	—	10.9	—	—	—	—	10.9	20.8

*Excluding Logan, 1937.

TABLE 1.—*Concluded.*

Variety	C. I. No.	State No.	Percentage bunt infection in 1932, 8 stations	1933, 6 stations	1934, 10 stations	1935, 9 stations	1936, 9 stations	1937, 10 stations	"Dwarf" smut, Logan 1937, %	Weighted average* %	Percentage of Kharkof
Minturki × Blackhull	11815	Nebr No 1099	—	—	—	—	—	9.8	58.0	9.8	21.4
Keliehor Russian	11569	Denton sel. No. 827	—	—	11.7	—	—	—	—	11.7	22.3
Minhardi × Minturki	8215	—	10.5	—	—	—	—	—	—	10.5	22.8
Oro × Fulhard	11585	Kans sel. No 332349	—	—	13.2	—	—	—	—	13.2	25.2
Turkey selection	11375	Colo No 351	—	—	13.6	—	—	—	—	13.6	26.0
Turkey selection	11818	Nebr sel. No 310362	—	—	—	—	—	12.2	61.2	12.2	26.7
Oro × Fulhard	11586	Kans. sel No. 332352	—	—	15.8	—	—	—	—	15.8	30.2
Minturki × Blackhull	11520	Nebr. sel No 2099	—	9.7	—	—	—	—	—	9.7	30.2
Minard × Minhardi	11656	Minn No 2313	—	—	—	16.3	—	—	—	16.3	30.8
Zemka	11522	—	—	9.9	—	—	—	—	—	9.9	30.8
Kawvale × Tenmarq	11669	Nebr. No 1086	—	—	—	19.1	—	—	—	19.1	36.1
Minturki × Blackhull	11519	Nebr sel No 2098	—	12.6	—	—	—	—	—	12.6	39.3
Turkey selection	11734	Nebr No. 1095	—	—	—	—	17.4	—	—	17.4	47.8
Mediterranean × Hope	11812	Denton No 41–22–11	—	—	—	—	—	22.2	82.0	22.2	48.6
Hungarian selection	11578	Nebr. sel No 31646	—	—	26.3	—	—	—	—	26.3	50.2
Turkey	6152	—	24.2	—	—	—	—	—	—	24.2	52.5
Minturki × Marquis	11657	Minn. No 2551	—	—	—	20.7	—	—	—	29.7	56.1
Marquis × Kanred	—	Hays Cereal No 312	27.3	—	—	—	—	—	—	27.3	59.2
Iobred	6934	—	—	—	31.8	—	—	—	—	31.8	60.7
P1066–1 × Burbank	10087	—	28.4	—	—	—	—	—	—	28.4	61.6
Hybrid L-5-5	11568	Denton No L-5-5	—	—	32.5	—	—	—	—	32.5	62.0
Enid	11508	—	—	20.0	—	—	—	—	—	20.0	62.3
Hostianium	7660	—	29.8	—	—	—	—	—	—	29.8	64.6
Nebraska No. 28	5147	—	30.2	—	—	—	—	—	—	30.2	65.5
Kawvale	8180	—	30.3	—	—	—	—	—	—	30.3	65.7
Kanred × Minturki	10012	North Platte No 14	30.5	—	—	—	—	—	—	30.5	66.2
Nebraska No. 60	6250	—	31.3	—	—	—	—	—	—	31.3	67.9
Turkey 102 (Goodwell)	—	—	32.5	—	—	—	—	—	—	32.5	70.5
Iowin	10017	—	32.6	—	—	—	—	—	—	32.6	70.7
Newturk	6935	—	32.7	—	—	—	—	—	—	32.7	70.9
Mediterranean × Hope	11813	Denton No 41–26–1	—	—	—	—	—	32.9	71.4	32.9	72.0
Marquis × Kanred	11374	Kans No 2679	33.4	—	—	—	—	—	—	33.4	72.5
Turkey 144 × Buffum	11741	So Dak No II–29–37–2	—	—	—	—	26.4	—	—	26.4	72.5
Turkey selection	11735	Nebr sel No 325648	—	—	—	—	26.5	—	—	26.5	72.8
Blackhull	6251	—	33.9	—	—	—	—	—	—	33.9	73.5
Minhardi × Minturki	8034	—	34.1	—	—	—	—	—	—	34.1	74.0
Kanred × Kanmarq	11573	Kans. sel. No. 30C1013	—	—	39.2	—	—	—	—	39.2	74.8

Kawvale × Tenmarq	11816	Nebr. sel No 23863	—	—	—	—	—	35 1	64.8	35.1	76.8
Hope × Kawvale	11814	Kans. sel. No. J342014	—	—	—	—	—	35 2	80 3	35.2	77.0
Mediterranean × Hope	11665	Denton No. 41-8-5	—	—	—	41 1	—	—	—	41.1	77.7
Pulcaster	6471	—	36.0	—	—	—	—	—	—	36.0	78.1
Tenmarq	6936	—	37 6	—	—	—	—	—	—	37.6	81.6
Kanred selection	10099	Colo. No 0106	37 6	—	—	—	—	—	—	37.6	81.6
Turkey selection	10083	Okla No 1	38 0	—	—	—	—	—	—	38.9	84.4
Kanred	5140	—	39 4	—	—	—	—	—	—	39.4	85.5
Denton	8265	—	39 9	—	—	—	—	—	—	39.9	86.6
(Minhardi-Minturki) × Tenmarq	11668	Nebr No 1085	—	—	—	46 8	—	—	—	46.8	88.5
Harvest Queen	6199	—	40 9	—	—	—	—	—	—	40 9	88.7
Kanred × Hard Federation	11574	Kans. sel. No 306327	—	—	46 7	—	—	—	—	46.7	89.1
Marquis × Kanred	11517	Hays Cereal No 315	—	28 8	—	—	—	—	—	28.8	89.7
Sibley No. 62	11523	—	—	28 9	—	—	—	—	—	28 9	90.0
Cumenay selection	11584	Kans sel No 316201	—	—	47 6	—	—	—	—	47.6	90.8
Beloglina selection	8884	North Platte No 11	42 0	—	—	—	—	—	—	42 0	91.1
Marquis × Kanred	11518	Hays Cereal No 3118	—	30 4	—	—	—	—	—	30.4	94.7
Quivira	8886	—	32.0	27 3	33 4	60 9	40 4	59.3	74 6	43 4	96.2
Cheyenne	8885	—	44 3	32 5	36 7	52.5	35 2	56 5	79.2	43.7	96.9
Kanred × Minhardi	10000	—	44 7	—	—	—	—	—	—	44.7	97.0
Kharkof (MacDonald College)	6686	—	45 3	—	—	—	—	—	—	45.3	98.3
Marquis × Kanred	11516	Hays Cereal No 313	—	31 6	—	—	—	—	—	31.6	98.4
Kharkof	1442	—	46 1	32 1	52 4	52 9	36 4	45 7	79 1	45.1	100.0
Mediterranean selection	11525	Tex sel. No 5933-23	—	32 2	—	—	—	—	—	32.2	100.3
Kanred × Hard Federation	11575	Kans. sel. No. 316065	—	—	53 6	—	—	—	—	53.6	102.3
Kanred × Marquis	10090	Kans. No. 2644	—	33 0	—	—	—	—	—	33.0	102.8
Karmont	6700	—	47.6	—	—	—	—	—	—	47.6	103.3
Kanred × Hard Federation	11373	Kans. No. 2671	50 0	—	—	—	—	—	—	50.0	108.5
Fulhard	8257	—	—	35.4	—	—	—	—	—	35 4	110.3
Turkey (Vaughn)	11509	Texas sel. No. 16	—	37 2	—	—	—	—	—	37.2	115.9
Tenmarq selection	10089	Kans. No. 2670	—	37 6	—	—	—	—	—	37 6	117.1
Mediterranean selection	11526	Tex. sel 5933-34	—	37.8	—	—	—	—	—	37 8	117.8
Tenmarq × Nebr. No. 28	11521	Kans. sel No. 304408	—	39 5	—	—	—	—	—	39 5	123.1
Keliehor Turkey	11679	Denton sel. No 318	—	—	—	66 5	—	—	—	66 5	125 7
Turkey 144 × Buffum	11739	S. Dak. No. II-29-25-4	—	—	—	—	48.1	—	—	48 1	132.1
Turkey 144 × Minhardi	11742	S. Dak No. II-29-36-1	—	—	—	—	48 3	—	—	48.3	132 7
Clarkan	8858	—	—	43 1	—	—	—	—	—	43.1	134.3
Turkey 144 × Buffum	11740	S. Dak. No. II-29-25-6	—	—	—	—	49 2	—	—	49.2	135 2
Blackhull selection	11737	Nebr. No. 1093	—	—	—	—	50 0	—	—	50 0	137 4
Kanred × Hard Federation	10091	Kans No. 2672	—	45 9	—	—	—	—	—	45 9	143.0
Early Blackhull	8856	—	—	46 5	—	—	—	—	—	46.5	144.9
Kanred × Hard Federation	10093	Kans. No. 2674	—	58 0	—	—	—	—	—	58.0	180 7
Average infection for varieties (excluding checks)			21 10	14.13	9 11	8 08	7 49	6 93			
Average infection for three susceptible checks			40 80	30 63	40 83	55.43	37 33	53 83			

*Excluding Logan, 1937.

Hope (C. I. 8178), which has been used with some success as a parent in crosses for the development of smut-resistant lines of spring wheat, appears in the present tests to be of little value for this purpose in winter wheat crosses. Although known to be resistant when planted in the spring it is susceptible when fall planted. For example, in the fall of 1936 at Arlington Farm, Arlington, Va., seed of Hope was tested with each of the races recently numbered by Rodenhiser and Holton (3). The variety was found to be resistant to only four of the 11 races of *T. tritici* and to none of the eight races of *T. levis*. Several of these races of *T. levis* are present in the Great Plains area and very probably account for the susceptible reaction of the Hope × Mediterranian and Hope × Kawvale crosses. It should be noted, however, that the H-44 (C. I. 8177), sister selection of Hope, when crossed with Minhardi (C. I. 5149), was resistant when tested at all stations in 1936.

Nurseries were planted in 1935 and 1936 at Logan, Utah, in cooperation with the Utah Agricultural Experiment Station, in order to determine the reaction of some of the hard red winter wheats to the so-called "dwarf" bunt organism, a race of *Tilletia tritici* prevalent in the Cache Valley. This bunt is known to be present also in Washington and Idaho, (2), and since it was first reported by Young (5), the writers have found it increasingly prevalent in the Gallatin Valley of Montana. The data obtained on the reaction to this organism are presented because of the possibility of its spread farther south and becoming a problem in the Great Plains area. The percentages of infection recorded in Table 1 are not, however, included in the averages obtained at the other stations. Ten of the 50 wheats tested showed less than 10% infection from this particular race of the "dwarf" bunt organism. The hybrid strains showing resistance apparently derived this resistance from their parents, Martin (C. I. 4463), Hussar (C. I. 4843), or Kanred (C. I. 5146). Oro, which possesses factors for resistance to a great many collections of *Tilletia* in the Great Plains tests, has no resistance to this race. Likewise, there is no resistance in all crosses in which Oro is one of the parents. The resistance of Ioturk (C. I. 11388) should be noted, as well as that of Relief (C. I. 10082), which was the only variety entirely free from the "dwarf" smut. Because of its resistance to this race, Relief is now being grown rather extensively in the Cache Valley of Utah. Unfortunately, it is susceptible to other races of *Tilletia* that are known to occur in this area and in the Northwest.

The present tests have been made at a number of stations under a wide range of environmental conditions and with bulk inoculum of a number of collections of *Tilletia*. Under these conditions, susceptible lines have been readily determined and rapidly weeded out. There is some doubt, however, regarding the reliability of results where varieties have been recorded as resistant. Since the inoculum consisted of a number of collections, relatively few chlamydospores of a particularly virulent race may have been present and as a result of this dilution the virulence of any one race would be masked. Oro, Hussar, and Minturki which were used in some of the crosses as bunt-resistant parents, together with some of the Turkey selections, therefore were

inoculated separately with individual races known to be present in the hard red winter wheat area and in the bulk inoculum.[4] In these tests, Oro, Hussar, the Turkey selections (C. I. 10016 and 10094), and Cheyenne selection (C. I. 11666) were all resistant to the individual races that have so far been identified in the hard red winter wheat area exclusive of Montana. Minturki was intermediate in its reaction to race L-3, which is known to be present in Kansas. The resistance of these wheats to all of the races found in Montana was not maintained. With the exception of Hussar they were highly susceptible to one race, L-8, and Hussar was intermediate in its reaction to L-6 and susceptible to T-8.

It is obvious from these data that bunt-resistant reactions obtained as a result of tests in which bulk inoculum is used should be considered in the nature of preliminary evidence and that such tests should be supplemented with others using at least the individual races present in the area to which the wheat is adapted and preferably all of the known races. Failure to do this may result in a repetition of the experience encountered with Yogo (C. I. 8033). In the uniform bunt nursery tests this variety was repeatedly classed as a resistant variety and as such was released for commercial production in 1935. That year Yogo, among other varieties, was inoculated with individual races and as a result was found to be highly susceptible to race L-8 now known to be generally distributed in Montana and the Northwest.

It is not within the scope of this paper to discuss further the importance of races of the bunt organism with relation to the wheat-breeding program. Pertinent data have been presented, however, in recent papers by Aamodt (1) and by Rodenhiser and Holton (3).

SUMMARY

Bunt nurseries of hard red winter wheat were grown for 1 to 6 years at 10 experiment stations in the Great Plains states and at Kearneysville, W. Va., St. Paul, Minn., and Logan, Utah. Each nursery contained 50 varieties and strains of winter wheat grown in duplicate rows. The inoculum used was a composite of collections of *T. levis* and *T. tritici* obtained from fields selected at random throughout the state in which the test or tests were made.

No variety or selection proved to be bunt-free at all stations, but a large number may be classed as resistant. Oro, Martin, and Hussar, and Minturki to a limited extent, contributed factors for resistance, in hybrid lines, to the races of the bunt organism used in these tests except those collected in Montana. The four above-mentioned varieties were susceptible when inoculated individually with certain races present in Montana and other wheat-growing areas.

Bunt-resistant reactions determined by experiments in which bulk inoculum is used should be considered as preliminary evidence only, and such tests should be supplemented by others in which the known races of *Tilletia* are used individually.

[4]This test was made at Pullman, Wash., and Bozeman, Mont., in cooperation with Dr. C. S. Holton.

Only 10 of 50 wheats tested proved to be resistant to the so-called "dwarf" smut race of *T. tritici* prevalent in the vicinity of Logan, Utah, and in the Gallatin Valley of Montana. Factors for resistance to this race are present in Martin, Hussar, Ioturk, and Relief.

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3. RODENHISER, H. A., and HOLTON, C. S. Physiologic races of *Tilletia tritici* and *T. levis*. Jour. Agr. Res., 55:483-496. 1937
4. WISMER, C. A. Inheritance of resistance to bunt and leaf rust in the wheat cross Oro X Tenmarq. Phytopath., 24:762-779. 1934.
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INFILTRATION CAPACITY OF SOME ILLINOIS SOILS[1]

R. S. Stauffer[2]

SOILS men have long recognized the necessity of defining observable features which may be used in differentiating soils. There is a growing appreciation among them of the need for the establishment of further physical and chemical criteria which cannot be observed in the field. The agronomists are now calling for information of this type, since the cropping behavior of a soil is frequently dependent on its physical and chemical properties, which can be determined only in the laboratory or in the field by laboratory methods.

The work reported in this paper has to do with one phase of moisture movement in soils, namely, infiltration capacity. The need for this type of information has become particularly pressing in recent years in connection with the widespread soil and water conservation efforts of the experiment stations and of the Soil Conservation Service.

The results reported in this paper are in the nature of a progress report, as there are many problems of technic and interpretation which remain to be worked out as the investigation progresses.

METHODS AND PROCEDURE

Tests were made at 14 locations scattered over the state of Illinois on soils which differ widely in infiltration capacities. These will be referred to by numbers 1 to 14, inclusive. With the exceptions of numbers 4, 5, and 6, the determinations were made on soils with a grass cover which had not been plowed for many years. Soils numbered 4, 5, and 6 occur on areas which had been seeded to grass the previous year.

The apparatus used and procedure followed in the investigation were similar to those reported by Musgrave,[3] with certain exceptions that will be noted. When the exact location for a test was selected the vegetation was removed by cutting it off with a sharp knife just flush with the surface of the soil. Cylinders 8 inches in diameter and long enough to reach into the B horizon were forced vertically into the soil to the desired depth by means of a hydraulic jack. A loaded truck was used to supply the necessary weight (Fig. 1). Perforated brass disks, which fit snugly inside the cylinders, were placed on the surface of the soil. A tent, large enough to cover all the cylinders, was set up so the determination could proceed in case of rain. The burettes, described below, were then placed in position (Fig. 2), filled with water, and measurements were started. Readings were taken at 5-minute intervals for 30 minutes, at 10-minute intervals for 1 hour, at 15-minute intervals for 1 hour, and at 30-minute intervals for 1½ hours. Thereafter hourly readings were taken till the whole period covered 24 hours or more with two exceptions which were continued for 22 hours.

Before the cylinders were forced into the soil they were covered both inside and outside with a thin coat of ordinary cup grease. This caused the cylinders to

[1]Contribution from the Division of Soil Physics, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication February 24, 1938.

[2]Associate in Soil Physics.

[3]Musgrave, G. W. The infiltration capacity of soils in relation to the control of surface runoff and erosion. Jour. Amer. Soc. Agron., 27:331–336. 1935.

penetrate the soil more easily and also lessened the likelihood of water passing down between the core of soil and the cylinder. In addition it was found that the soil column was not so likely to be depressed in the cylinder. In fact the reason

FIG. 1.—Equipment for forcing cylinders into the soil

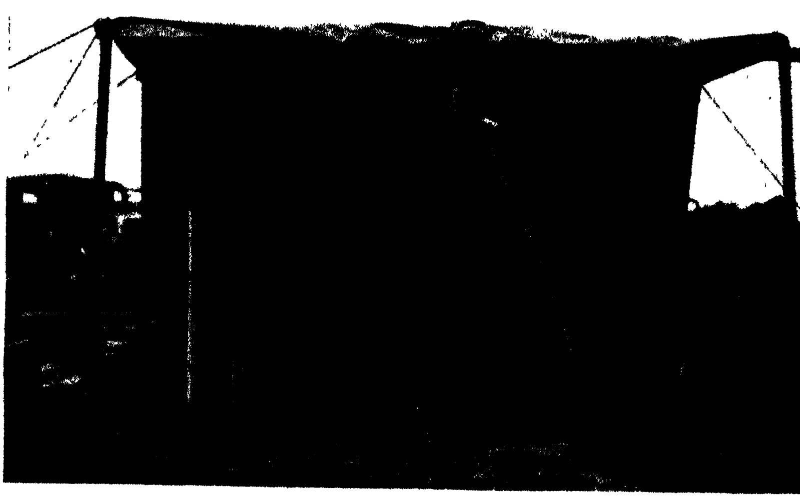

FIG. 2.—Cylinders, burettes, and part of tent in position.

grease was used on the cylinders was because the first soil on which measurements were attempted compressed very badly as the cylinder was forced downward into the soil. After applying the grease this did not occur, and since the grease did not penetrate the soil mass, it was decided to use it regularly.

The burettes, which have a capacity of 3,600 cc, were made of galvanized iron down-spouting. The down spouting was cut into desired lengths, the seams soldered tightly, and short copper tubes for inlets and outlets were soldered on the ends. A glass tube for making the readings was graduated at 10-cc intervals and was connected to the spouting near the ends.

The amount of evaporation was determined by putting a measured amount of water at the beginning of a test into a container of the same diameter as the cylinders. The surface of the water in this container was about the same distance from the top of the container as the water in the cylinders was from the tops of the cylinders. At the end of a test the water in the container was measured again. The difference was the amount of water evaporated.

Since the viscosity of water is affected by changes in temperature, it seemed desirable to get some idea of the temperature variation. The temperatures of the water in the cylinders and of the soil at a depth of 3 inches were recorded several times during the day and night while a determination was in progress.

At the time of a determination, samples of soil were taken near the cylinders for moisture determinations. Since the percentage of water in a soil does not convey much meaning unless additional information is available, the "relative wetness" as described by Conrad and Veihmeyer[4] is used. It is the percentage of water in the soil divided by the moisture equivalent times 100.

DESCRIPTION OF THE SOILS

Soils numbered 1, 2, and 3 occur in the brown-gray area[5] of southwestern Illinois. Soil number 1 is characterized as brown-gray silt loam on tight clay. It was formed from loess or loess-like material and occurs on level or nearly level topography. The surface soil is a dark grayish-brown silt loam, with small, granular, well-developed but easily broken down, structure particles. The B horizon ,which is very plastic, possesses fairly well-developed prismatic structure. Glacial till could not be definitely identified until a depth of 95 inches had been reached. No calcareous material was encountered to a depth of 125 inches.

Soils numbered 2 and 3 are slick spots which are characteristic of this area of Illinois and which make up a considerable percentage of the area. They have a shallow, gray surface soil and possess very slight structure development anywhere in the profile. Number 2 was calcareous at 17 inches and this continued down to a depth of 45 inches, below which it was not calcareous. Soil number 3 is similar to number 2 except it had reached a more advanced stage of slick spot development. It was calcareous at a depth of 13 inches.

Soils numbered 4, 5, 6, and 7 occur in the southern part of Illinois south of the glaciated area. They have apparently been developed from loess deposited on residual material. The depth to bed-rock, a red, fine-grained sandstone, ranged from 90 inches in number 6 to 122 inches in number 7. Numbers 4 and 5 occur on an 8% slope. The test was made on number 5 about 10 rods from the top of the slope and on number 4 about 10 rods further down the slope. Soil number 6 occurs on a 5% slope and number 7 on a nearly level area on the top of a hill about 6 rods from the nearest break in the relief. Soils numbered 4, 5, and 6 are very similar. The surface soils are shallow, grayish yellow, silt loams. While these soils are not highly plastic they are very compact throughout the profile. Soil number 7

[4]CONRAD, JOHN P., and VEIHMEYER, F. J. Root development and soil moisture. Hilgardia, 4:4. 1929.

[5]SMITH, R. S., *et al.* Parent materials, subsoil permeability, and surface character of Illinois soils. Univ. Ill. Agr. Exp. Sta. 1935.

differs from the other three chiefly in that it has a deeper and darker colored surface soil, due probably to the fact that it has been less eroded.

Soil number 8 is a grayish dark brown, heavy silt loam or clay loam on clay and is characteristic of the grayish brown area of west central Illinois.[6] It occurs chiefly where the topography is nearly level. The surface soil is deep and possesses a well-developed, finely granular, structure. The parent material of this soil is loess, which at this location is about 100 inches deep. Soil number 9 is similar to number 8 except that it occurs on slightly higher ground. The surface soil is lighter in color and apparently less plastic than that of number 8, but the B horizon seems to be more plastic.

The descriptive name of soil number 10 is brown silt loam. It was formed from loess and occurs on undulating topography. The surface soil is brown in color and possesses a granular condition. The B horizon is slightly plastic, but water passes through it readily. No glacial till was encountered to a depth of 120 inches where this determination was made. Carbonates were found at a depth of 45 inches. This soil is typical of the soils that occur in the deep loess area of northwestern Illinois.

Soil number 11 is similar to number 10 except that it occurs on more rolling topography, and the surface soil is lighter brown in color. The B horizon shows only slight accumulation of fine material and permits water to pass through readily. No carbonates were found to a depth of 70 inches and at the location where this determination was made the loess was more than 100 inches in depth.

Soil number 12 is described as brown silt loam on compact, medium plastic, calcareous till. It occurs where the topography is undulating to gently rolling. The surface soil is dark brown clayey silt loam or clay loam, and is well granulated. The B horizon is plastic and like the underlying till seems to be relatively impervious to water.

The descriptive name of soil number 13 is gray silt loam on tight clay. It occurs on the flat prairie areas of Illinois on what is known as the Lower Illinoian Glaciation. Water does not penetrate this soil readily because of the tight B horizon and also because of the underlying Illinoian gumbotil.

Soil number 14 is described as brown silt loam on till. It occurs on the older parts of the Wisconsin drift area where the topography is rolling. The A horizon is brown silt loam. The B horizon, which apparently was developed from drift, is only slightly plastic. The whole profile is readily permeable to water.

RESULTS AND DISCUSSION

The infiltration capacities of the soils included in this study are given in the form of graphs in Fig. 3, which covers a 2-hour period, and in Fig. 4, which covers a 24-hour period. Each graph represents the average of a number of individual determinations, ranging from 5 to 10. Since this is probably too small a number to be treated statistically the extremes and averages of all individual determinations in each setup are given in Table 1, for 1, 2, and 24 hours. The amount of water in surface inches evaporated during the 24-hour period of each setup is also given in Table 1.

In both Figs. 3 and 4, the graphs for soils 10, 11, and 14 run off the paper. This seemed less undesirable than to use a smaller scale which would throw the graphs of the other soils too closely together to be distinguished. Furthermore, so far as the graphs in Fig. 4 are concerned, it is doubtful whether the results after 10 or 12 inches of

[6]See footnote 5.

water were absorbed are of any significance because that amount of water would ordinarily be sufficient to saturate the soil column to the bottom of the cylinders. Any additional water could not be considered as the amount of water a given area of soil would absorb because of the horizontal spreading of the water below the cylinder. The total average infiltration capacities of soils 10, 11, and 14 for 1, 2, and 24 hours can be seen in Table 1.

TABLE 1.—*Minimum, maximum, and average infiltration in surface inches of all determinations made on each soil and evaporation during the determination.*

Soil No.	1 hour			2 hours			24 hours			Evaporation, surface inches
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	
1	0.63	0.88	0.78	1.09	1.31	1.22	3.17	9.87	6.22	0.12
2	0.27	0.47	0.37	0.41	0.64	0.54	0.95*	1.20	1.10	0.11
3	0.03	0.34	0.15	0.04	0.39	0.18	0.34*	0.58	0.47	0.11
4	0.15	0.78	0.60	0.37	1.33	1.06	1.41	2.46	2.07	0.10
5	0.38	1.25	0.73	0.72	1.33	1.06	1.46	2.29	1.88	0.10
6	0.19	0.81	0.45	0.27	1.05	0.67	1.48	1.89	1.62	0.08
7	0.19	0.59	0.34	0.36	0.90	0.56	2.13	2.69	2.36	0.07
8	0.77	1.19	0.96	1.18	1.60	1.36	2.29	6.22	3.91	0.14
9	0.25	0.62	0.41	0.40	0.89	0.56	1.18	3.98	2.16	0.14
10	3.35	7.75	5.36	5.87	12.09	9.00	35.66	65.58	48.10	0.11
11	3.96	10.58	5.91	6.52	19.61	10.58	40.33	69.85	58.57	0.10
12	0.11	0.99	0.71	0.13	1.07	0.78	0.74	2.55	1.45	0.12
13	0.03	0.67	0.34	0.16	0.80	0.43	0.56	1.57	0.98	0.06
14	2.00	5.30	3.70	3.24	10.74	6.68	23.37	52.43	35.96	0.12

*For 22 hours.

Since it was not clear how to make proper corrections for variation in the viscosity of the water due to temperature differences, such corrections are not attempted. The widest range in temperature of the water for a 24-hour period was 7° C and for that of the soil at a depth of 3 inches, 3°. The extreme range of temperatures during the whole series of determinations was 15° for the water and 14° for the soil. At Urbana, Ill., during this same period, the soil temperatures at a depth of 24 inches varied 6° C and at a depth of 8 inches, 13°. The temperature ranges for these depths are given because 24 inches is deep enough to reach into the B horizon of most soils, probably the least permeable portion of the profile, and 8 inches is as deep as the added water penetrated several of the soils included in this study.

The amount of water already in a soil when a test is being made will influence the results on infiltration capacity. The results of the moisture determinations made in this study are given in Table 2. They show that the moisture contents of most of the soils were relatively high.

No correction is made for the loss of water by evaporation because the evaporation was measured for the whole period of a determination and not for specific periods during the determination. Therefore, it is not known just how much to deduct from the total amount of water measured at any particular time interval. The amount of evaporation was insignificant in many cases, but when the infiltration capacity of a

soil is as low as that of number 3 the amount of water evaporated in 24 hours made up about 23% of the total amount of water measured by the burettes.

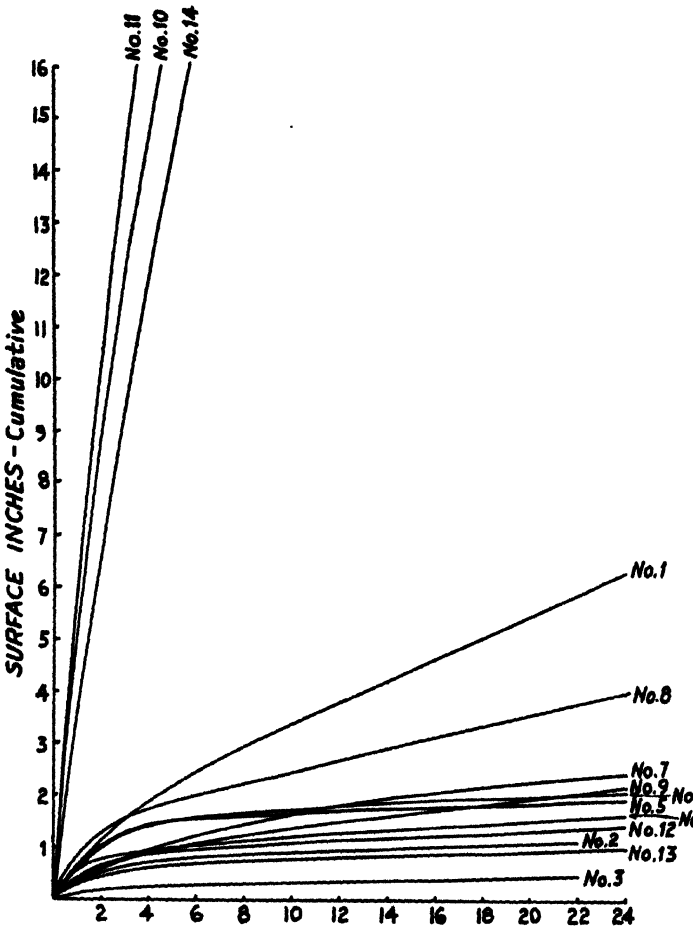

FIG. 3.—Infiltration capacity in surface inches of some Illinois soils for a 2-hour period.

Another factor that would be responsible for considerable variation in the infiltration capacity of the same soil type is the condition of the surface soil. As stated previously, the soils included in the study reported in this paper were under grass cover and in all but numbers 4, 5, and 6 had not been plowed for many years. If determinations were repeated on the same soil types but which had a different surface condition, due perhaps to being farmed, the results would un-

doubtedly differ from those reported here. This would be particularly true at the beginning of a run. For this reason care must be exercised in using such results in connection with erosion control measures,

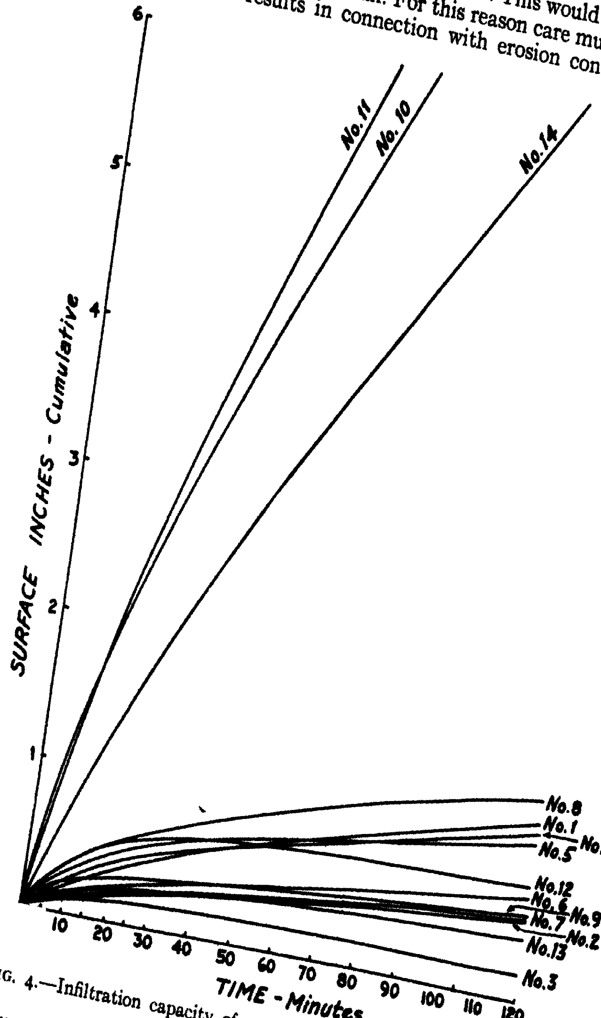

FIG. 4.—Infiltration capacity of some Illinois soils for a 24-hour period.

unless, as stated by Musgrave,[7] the results of such measurements giving the minimum capacity of the soil in question be used.

By the method employed in this study a head of water from 5 to 7 mm in thickness was maintained on the surface of the soil. Under such conditions the penetration of water might be interfered with because

[7]*Loc. cit.*

the air confined in the soil could not escape readily. However, it is doubtful if the conditions under which these tests were conducted are less favorable for the escape of confined air than those which obtain during the most intense rains. This would be particularly true for soils that are slowly permeable.

TABLE 2.—*Field moisture content, moisture equivalent, and relative wetness of some Illinois soils.*

Soil No.	Moisture content*			Moisture equivalent			Relative wetness		
	A_1	A_2	B	A_1	A_2	B	A_1	A_2	B
1	22.8	23.2	24.2	23.1	26.1	27.6	98.7	88.9	87.7
2	16.4	21.6	27.1	24.3	—†	—†	67.5	—†	—†
3	17.7	16.3	21.2	19.5	—†	—†	90.8	—†	—†
4	21.4	26.6	27.5	22.0	26 6	28.3	97.3	100 0	97.2
5	17.3	24.1	27.1	18.7	25.6	27.5	97.9	94.1	98.5
6	23.8	23.8	25.9	22.2	24.7	28.0	107.2	96.4	92.5
7	17.2	20.0	24.2	21.9	21.8	29.5	78.5	91.8	82.0
8	24.2	28.0	33.2	26.4	28.4	35.6	91.7	98.6	93.3
9	24.7	24.7	29.3	25.5	26.5	30.3	96 9	93.2	96.7
10	24.0	24.8	24.0	27.9	29.3	29.1	86 0	84.6	82.5
11	29.0	31 1	29.1	27.9	30.3	29.1	103.9	102.6	100.0
12	30.2	25.6	28.2	34.4	28 8	30 7	87 8	88 9	91.9
13	25.2	22.2	23.9	24.8	22.4	26.9	101.2	99.1	88.8
14	22.2	24.8	25.2	23.8	23.6	24 9	93 3	105.1	101 2

*Percentage by weight, oven-dry basis
†Could not determine moisture equivalent because water would not pass through soil, therefore, could not determine relative witness.

It is interesting to note the graphs for soils numbered 4 and 5, particularly in Fig. 4. These graphs are the same shape and remain close together during the whole 24 hours of the determination. As mentioned previously, these two setups were made on the same slope. Soil number 5 was 10 rods farther up the slope than soil number 4.

SUMMARY AND CONCLUSIONS

1. The infiltration capacities of several Illinois soils were determined at 14 locations.

2. The results indicate that at three of these locations the soils have high infiltration capacities and at 11 of the locations they have low infiltration capacities.

3. There are a number of factors which may cause the infiltration capacities of soils to vary, but the dominant factor seems to be the physical character and condition of the soils themselves.

4. The main purpose of this project is to secure information that will be of value in characterizing soils and in soil and water conservation. However, to characterize a soil on this basis more determinations than have been made are necessary. Furthermore, it seems that these determinations should be made at locations selected to give the range covered by the soil type in question, rather than at locations where the soil is considered "typical," as is frequently done.

SEED SETTING AND AVERAGE SEED WEIGHT AS AFFECTED BY TWO METHODS OF OPENING BARLEY FLOWERS FOR EMASCULATION[1]

O. T. BONNETT[2]

EMASCULATION and cross-pollination of barley is a tedious and time-consuming process and any method that will bring about an increase in the percentage of seed set and an increase in the average weight a seed is of value. If, in cross-pollination, a high percentage of the flowers set seed, the number of flowers that must be crossed to obtain a given number of seeds can be reduced and thus bring about a saving in time and effort. Furthermore, crossed seed as near the same size as the naturally produced parent seed is also desirable when the growth of the F_1 plants is to be compared with that of their parents.

Tschermac (4)[3] has described the technic of crossing wheat, oats, rye, and barley. He opened barley flowers for emasculation and artificial cross-pollination by cutting off the upper one-third to one-half of the tips of the lemmas and paleas. Pope (2) described a rapid method for making small grain hybrids. His method was concerned with the manner of applying pollen to the emasculated barley flowers and not with the method of opening the barley flowers for emasculation. Woodworth and Bonnett (5) published a photograph showing the two methods of opening barley flowers that are more fully discussed in the present article.

In the present paper a description will be given of two methods of opening barley flowers for emasculation and cross-pollination and data showing the effect of the two methods upon seed setting and seed size will also be presented. In addition, data will be given showing the effect of mutilating barley flowers in different ways upon the average seed weight.

METHODS OF EMASCULATION

Barley heads were prepared for emasculation in the usual way. In Fig. 1 the various manipulations in preparing a barley head for emasculation are shown. When the awns extend 3 to 4 centimeters above the last blade (Fig. 1, A), the head is removed from the boot (Fig. 1, B and C). The base and tip spikelets are cut off with sharp-pointed scissors, leaving a number of spikelets in the middle of the head, and the side spikelets are also pulled or cut off (Fig. 1, D). The barley head is now ready for emasculation (Fig. 1, E).

Two methods of opening barley flowers were used. Both methods are shown in Fig. 1, F, and in Fig. 1, G, the latter figure being an en-

[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication February 24, 1938.

[2]Assistant Chief in Plant Genetics.

[3]Figures in parenthesis refer to "Literature Cited", p. 506.

largement of a portion of the head in Fig. 1, F. The flowers on the left side of the head have had the awns and tips of the lemmas and paleas cut off just above the anthers. The anthers were then removed

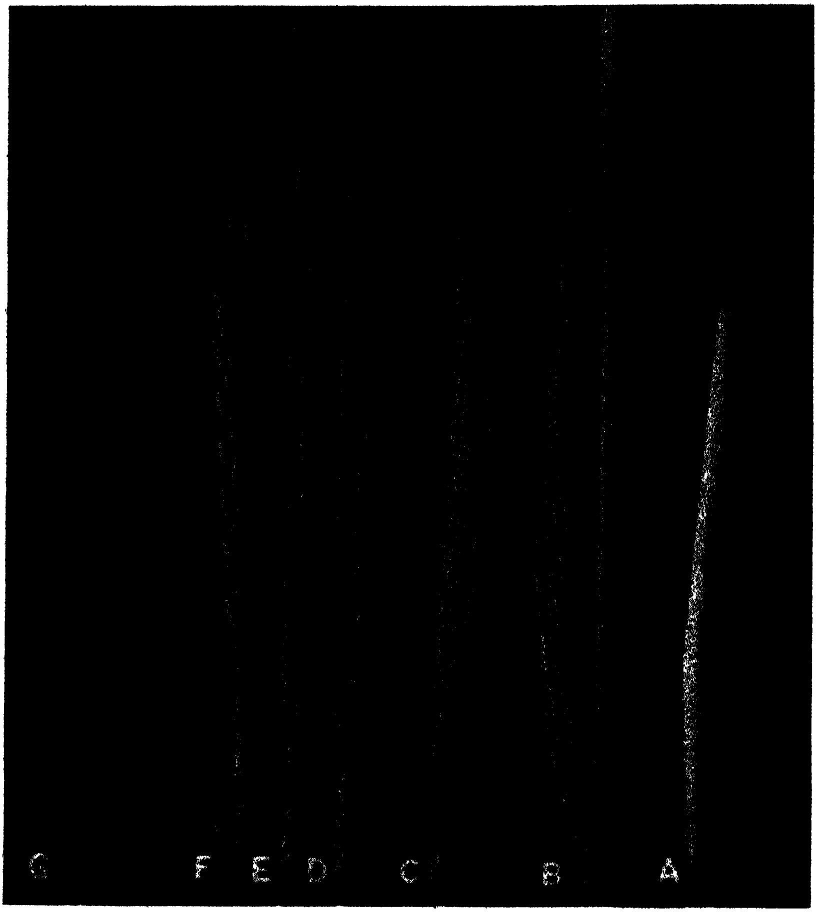

FIG. 1.—Various steps in the preparation of a head of six-row barley for emasculation. A, Appearance of a head of barley at about the proper stage of development for emasculation; B, the head, partly removed from the boot; C, the head, free of the boot; D, part of the basal, tip, and side spikelets removed; E, the spike, ready for emasculation; F, on the left side of the spike, the awn and tip of the flowering glumes removed; on the right side of the spike, awns normal lemmas slit; G, enlargement of a portion of F.

through the opening at the top of the flowers by means of small-pointed tweezers. On the right side of the spike the flowers have been opened by slitting the lemma with one point of the tweezers which had been sharpened for this purpose. Through the slit made in the lemma the anthers were removed and pollinations were made.

EXPERIMENTAL RESULTS

A comparison was made of the effect of the two methods of opening barley flowers upon the percentage of flowers setting seed and upon the average weight of a seed. Wisconsin Pedigree No. 5, a six-row barley, was used as the pistillate parent and Spartan, a two-row barley, was used as the pollen parent. The plants were grown in pots in the greenhouse and at the proper stage for emasculation the heads of Wisconsin Pedigree No. 5 were prepared and the flowers opened as shown in Fig. 1, F, i. e., the lemmas and paleas of the flowers on one side of the head were cut off and the lemmas of the flowers on the other side of the head were slit. Two to three days after the flowers were emasculated both sides of the head were pollinated.

Differences were found in the percentage of flowers setting seed and in the average weight of the seeds. Of 61 flowers prepared for emasculation and cross-pollination by cutting off the glumes, 39, or 63.9%, of the flowers set seed which weighed, on the average, 38.8 milligrams a seed. Of 62 flowers opened for emasculation and cross-pollination by slitting the lemmas, 53, or 85%, of the flowers set seed which weighed, on the average, 43.5 milligrams a seed. There was an increase of 35.9% in the number of flowers setting seed and an increase of 12.1% in the average weight a seed in favor of the method of opening the flowers by slitting the lemmas.

Differences in seed size and seed setting are shown in Fig. 2. On the left the tips of the lemmas and paleas were cut off and on the right the lemmas were slit. The apparent differences in seed setting and seed size are greater than are indicated in the data given above. This is because the heads of barley shown in the illustration were grown at a different time than the heads from which the data on seed setting and seed size were taken. However, the illustration shows quite clearly the two methods of opening flowers.

Another experiment was conducted to determine the effect of methods of mutilating barley flowers upon the average weight of the seed. Spartan was grown in the field, and at the proper stage for emasculation the flowers were mutilated and allowed to self-fertilize. The flowers were mutilated in the following ways: (a) Awns cut off at the tip of the lemma, (b) glumes cut off to various lengths, and (c) the glumes slit. One-half of a head was mutilated in one way and the other half of the head in a different way. By mutilating each half of a head differently a better comparison could be made between the methods.

In Table 1 is given: (a) a comparison between certain methods of mutilation in their effects upon the average seed weight, and (b) a summary of the results.

Essentially the same conclusions are reached from a study of the summary as are obtained from a study of the paired methods of mutilation. Compared to the unmutilated flowers, slitting the lemmas produced the least reduction in average seed weight. Removing the awns brought about a slightly greater reduction in average seed weight than slitting the glumes. Cutting off the lemmas or paleas to a length of 7 to 8 mm caused a greater reduction in average seed weight than slitting the glumes, and cutting the lemmas and paleas to a length of 4 to 5 mm caused the greatest reduction in average seed weight.

Except where the lemmas and paleas were cut off to a length of 4 to 5 mm different methods of mutilation did not appear to make any real difference in the average number of seed set. When the lemmas

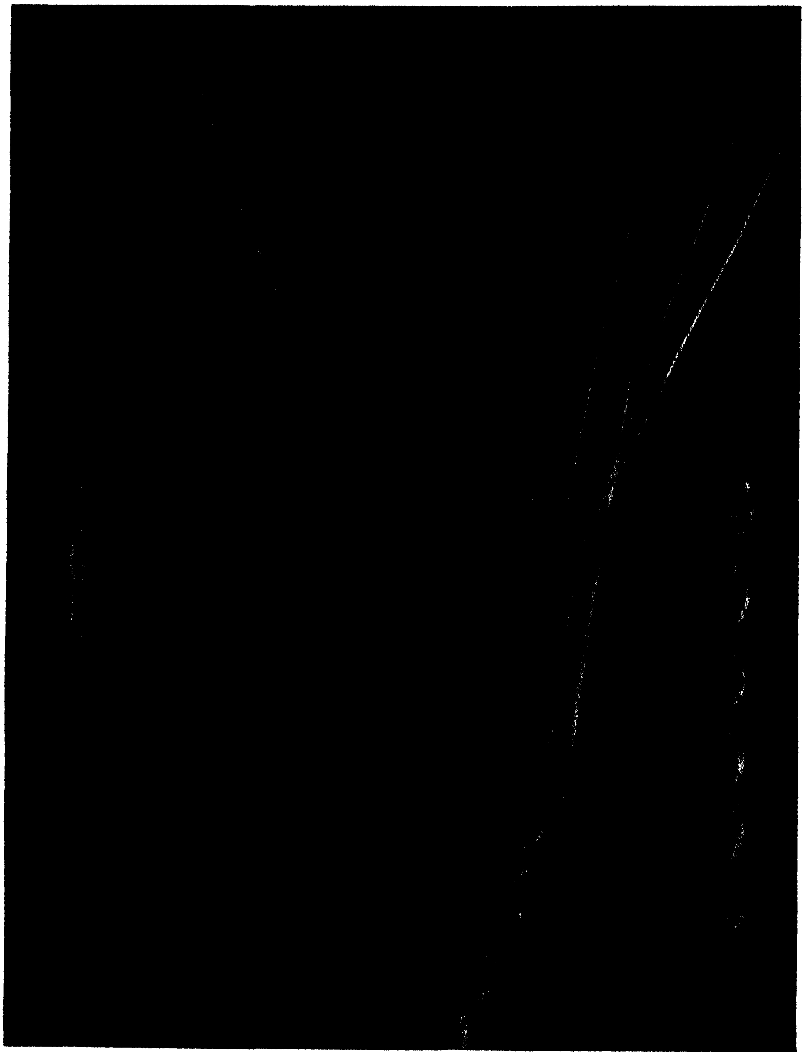

Fig. 2.—Showing the effect of two methods of opening barley flowers for emasculation upon the size of seed. Left, flowering glumes cut off; right, lemmas slit.

and paleas were clipped to 4 to 5 mm the tips of some of the anthers were also cut off, which probably interfered with the production of viable pollen and therefore reduced the percentage of flowers setting seed.

TABLE 1.—*Average weight of barley seed as affected by mutilating barley flowers in different ways and permitting them to self-fertilize, each half of a head having been mutilated in a different way.*

Kind of mutilation given respective halves	Total half heads	Total seeds	Average seed a half head	Average seed weight, mg	Difference	Difference as per cent of lower value
Awns left on, flowering glumes normal	2	18	9.0	53.05		
Awns left on, flowering glumes slit	2	17	8.5	44.70	8.35	18.68
Awns left on, flowering glumes normal	4	34	8.5	48.23		
Awns removed, flowering glumes normal	4	38	9.5	42.10	6.13	14.56
Awns removed, flowering glumes normal	4	37	9.2	39.59		
Awns removed, flowering glumes normal	4	35	8.7	39.42	.17	.04
Awns left on, flowering glumes slit	9	82	9.1	40.54		
Awns removed, flowering glumes clipped to 7-8 mm*	9	85	9.5	32.82	7.72	23.52
Awns left on, flowering glumes normal	7	58	8.2	48.44		
Awns removed, flowering glumes clipped to 4-5 mm	7	46	6.5	19.13	29.31	153.21
Awns left on, flowering glumes slit	10	86	8.6	42.09		
Awns removed, flowering glumes clipped to 4-5 mm	10	71	7.1	21.97	20.12	91.57
Summary						
Awns left on, flowering glumes normal	13	110	8.4	49.13		
Awns left on, flowering glumes slit	21	185	8.8	41.65	7.48†	17.95
Awns removed, flowering glumes normal	12	110	9.1	40.40	8.73	21.60
Awns removed, flowering glumes clipped to 7-8 mm	9	85	9.0	32.82	16.31	49.69
Awns removed, flowering glumes clipped to 4-5 mm	17	117	6.8	20.85	28.28	135.63

*Normal flowering glumes 10-12 mm long.
†All differences in the summary are differences from the normal.

It has been shown by Harlan and Anthony (1) and by Rosenquist (3) that the removal of the awn on heads of barley and wheat decreased the average weight of seed. It has been further shown by the data presented here that other kinds of mutilation also reduce the average weight of seed compared with that of seed produced in unmutilated flowers.

From the data presented in this paper a general conclusion may be stated as follows: When a high percentage of well-developed seed

from cross-fertilization is desired, the least possible degree of injury in emasculation should be the primary objective of the operator and opening the flowers by slitting the glumes seems more nearly to meet this objective than when the flowers are opened by cutting off the tips of the lemmas and paleas.

SUMMARY

1. Barley flowers were opened for emasculation and cross-pollination in two ways, *viz.*, (a) the lemmas and paleas of the flowers were cut off just above the tips of the anthers, and (b) the lemmas were slit. Slitting the lemmas resulted in the production of 21.5% more crossed seed and 10.8% heavier crossed seeds than where the tips of the lemmas and paleas were cut off.

2. Different methods of mutilating barley flowers and permitting them to self-fertilize resulted in differences in the average seed weight. The methods of mutilation and the average seed weights were as follows: Normal flowers (awns left on and glumes normal), 49.13 mg; awns left on, flowering glumes slit, 41.65 mg; awns removed, flowering glumes normal, 40.4 mg; awns removed, flowering glumes clipped to 7 to 8 mm, 32.82 mg; and awns removed, flowering glumes clipped to 4 to 5 mm, 20.85 mg.

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QUANTITY AND RELATIONSHIPS OF CERTAIN ELEMENTS IN MICHIGAN LEGUME HAYS[1]

C. E. MILLAR[2]

A LARGE number of data relative to the chemical composition of alfalfa, sweet clover, and red clover have been collected in the past 13 years by the Soils Section of the Michigan Agricultural Experiment Station. Although portions of these data have been published, no attempt has been made to compile or correlate the results of the various studies. This paper attempts to summarize all such data and to interpret the results statistically.

As the primary object of the paper is to present these findings from a mathematical standpoint, it is unnecessary to dwell upon the experimental methods employed in collecting the data. Detailed procedures and data may be found in the indicated references. It should be mentioned, however, that the plant samples were placed directly in bags in the field, and hence were not subject to loss of parts or to chemical changes resulting from handling, curing, and storage in the hay-making process.

In interpreting the results, the popular "coefficient of linear correlation" and its "standard error of prediction" are used. Experimental significance is attributed to the results in which the correlation coefficient is greater than twice its standard error. Less difference is considered insignificant because it might have been due to chance or experimental error alone. In the discussions, free use is also made of Student's odds method to show significance, odds of greater than 20:1 being considered significant.

CONTENT OF CERTAIN NUTRIENT ELEMENTS IN MICHIGAN ALFALFA HAY

Table 1 shows the average percentage of N, P_2O_5, K_2O, CaO, and MgO contained in Michigan alfalfa. The number of samples analyzed is also shown. The plants were grown on various soil types. Seasonal variation was smoothed out by selecting samples over a period of 13 years. Some plants received fertilizer, others none. Some were cut early, some cut late. Soils varied from neutral to strongly acid, with various quantities of lime applied. The analyses herein considered are in effect then a random sampling of Michigan alfalfa, and may be justifiably considered as representative of such. The data show Michigan-grown alfalfa to be higher in nitrogen, phosphorus, calcium, and

[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Approved for publication by the Director as journal article 301 n. s. of the Michigan Agricultural Experiment Station. Received for publication March 1, 1938.

[2]Professor of Soils. The analyses on which this paper is based are the work of several former members of the Soils Section. The writer is indebted to Mr. A. Mick, graduate assistant and Mr. W. Andrews of the Mississippi Station, former graduate assistant, for the compilations and assistance in preparation of the paper.

magnesium than average alfalfa hay of the United States as reported by Morrison.[3] On the other hand, the content of potassium is lower.

TABLE 1.—*Quantities of nutrients contained in Michigan alfalfa grown on heavy and light soils and in average alfalfa hay for the United States.*

Constituent	Heavy soil			Light soil			Difference		Average for U. S.*
	No. of samples	Mean %	S. D. of mean	No. of samples	Mean %	S. D. of Mean	%	S. D.	
N	71	3.33	±.062	103	2.95	±.045	0.37	±.077	2.35
P_2O_5	75	0.69	±.020	109	0.54	±.014	0.15	±.024	0.48
K_2O	74	2.04	±.102	30	1.35	±.079	0.69	±.12	2.43
CaO	76	2.57	±.066	119	3.21	±.110	0.64	±.13	2.00
MgO	74	0.65	±.0151	40	0.75	±.040	0.10	±.043	0.43

*From Morrison's "Feeds and Feeding".

During many years of field experimental work, it has been observed that fertilizer is more essential for an abundant growth of alfalfa on light than on heavy soils. The statistical data presented in the two divisions of Table 1 offer one explanation of this observation. The heavy soil group includes Brookston, Miami, Kewanee, and Hillsdale, as compared to the lighter soils, Fox, Coloma, Rubicon, Mancelona, and Plainfield. That differences in composition are highly significant is shown by the fact that difference in the means far exceeds twice the respective standard deviation in every case. The large number of samples analyzed strengthens this conclusion. It is interesting to note that alfalfa grown on heavy soil contains more N, P_2O_5, and K_2O, but less CaO and MgO than that grown on light soil. In the first group of soils lime occurs much nearer the surface in the profile than in the latter group. Very little alfalfa is grown on the lighter soils without application of lime, but on the heavy soils mediocre to good crops are obtained in many cases without lime.

RELATIONSHIPS BETWEEN NUTRIENT ELEMENTS IN ALFALFA HAY

Table 2 shows the relationships which exist between the quantities of nutrient elements contained in alfalfa hay.

Using 147 random selected analyses, it was found that the nitrogen content is closely associated with the phosphorus content, the correlation coefficient being 0.75 with a standard error of ± .036. This positive correlation indicates that the relationship between the percentages of these two nutrients is direct, that is, the nitrogen content increases as the phosphorus content increases, and *vice versa*. The small standard error of prediction indicates, moreover, that the scatter about the line of best fit is relatively small. This obvious association between nitrogen and phosphorus is, however, no more than is to be expected, for both are constituents of several proteins in a fairly fixed ratio. If the total percentage of both were confined to these

[3] MORRISON, F. B. Feeds and Feeding. New York: Morrison Pub. Co. Ed. 20. 1936.

proteins then the correlation coefficient would more closely approach 1.00. That it fails to do so is due, of course, to the fact that other forms of nitrogen and phosphorus are present in the plant tissue—forms in which they are not so definitely related or perhaps forms in which the association may be inverse.

TABLE 2.—*The relationship of certain of the nutrient elements in alfalfa hay grown in the field.*

Factors being correlated		Number of samples	Coefficient of correlation	Standard error of prediction	Constants	
x	y				a	b
N	P_2O_5	147	+.75	±.036	−0.232	0.263
N	K_2O	77	+.50	±.086	−0.467	0.756
N	CaO	159	−.33	±.071	4.943	0.633
N	MgO	85	+.30	±.099	0.420	0.073
K_2O	P_2O_5	88	+.43	±.088	0.528	0.088
MgO	P_2O_5	87	+.41	±.090	0.410	0.392
CaO	P_2O_5	167	−.41	±.065	0.823	−0.074
CaO	MgO	98	−.28	±.093	0.859	−0.059
CaO	K_2O	91	−.21	±.101	2.494	−0.206

Positive correlation coefficients are also evident between nitrogen and potassium; between nitrogen and magnesium; and between phosphorus, potassium, and magnesium, although the relationships are not so obvious as that above. These positive correlations also mean that the percentages of both members of the above pairs are either high or low. The lower values of the coefficient, however, indicate that the relationship is not great; and in addition, the large standard error of prediction values indicate that the scatter of the plotted points around the line of best fit is more widespread than in the nitrogen-phosphorus relationship.

The remaining nutrient pairs in Table 2, nitrogen-calcium, calcium-phosphorus, calcium-magnesium, and calcium-potassium, all have a negative correlation. This means that instead of both members of the pair being either low or high, the relationship is opposite or inverse. For instance, as the percentage of nitrogen rises the percentage of calcium in the tissue falls; or if the percentage of nitrogen is low, the calcium content is apt to be high. These relationships, however, are even less marked than those with positive coefficients. This is shown by the smaller value of the coefficient and the increasing magnitude of the respective standard error of prediction. The last case, in fact, shows so small a difference between the correlation coefficient and its standard error as to be practically insignificant. The relationship here is extremely doubtful, if existing at all. A graph of the percentage values would show a widespread scatter, while the location of the line of best fit would be very vague.

The relationships between quantities of the nutrient elements in alfalfa found in this study are in general agreement with the relationships found in woody plants by several investigators.[4]

[4]Data summarized in Fundamentals of Fruit Production by Gardner, Bradford, and Hooker (pages 130–160).

Table 2 is of value as it shows the effect of changing the percentage of one constituent on the percentages of other constituents. For example, the usual purpose of fertilizing soil for an alfalfa crop is either to increase the yield or to improve the hay quality by producing a change in the percentage of one or more constituents. If the protein content of alfalfa were increased by inoculation or soil treatment, it might be convenient to predict the effect of the increase on the percentages of other nutrients present.

For convenience, in the last two columns of Table 2 are the constants to substitute in the equation $Y = a + bx$ for determining the probable percentage of one element in plant tissue when the percentage of another is known. If the percentage of one nutrient element (x) is known, the percentage of the other (y) may be estimated by substituting the proper constants. For the nitrogen-phosphorus relationship, substitution gives $Y = -0.232 + 0.263\,x$, or percentage of phosphorus = $-0.232 + 0.263$ (percentage of nitrogen).

EFFECT OF LIMING THE SOIL ON THE PHOSPHORUS CONTENT OF ALFALFA LEAVES

The data in Table 3 indicate that all applications of lime decreased the phosphorus content of alfalfa leaves These decreases are significant as indicated by Student's odds. It should be noted, however, that the small application resulted in as large a decrease as did the heavy applications. The odds that 12,500 pounds of limestone decreased the phosphorus content more than any other application are only 5:1 which is insignificant. The obvious conclusions are that applications of lime decrease the phosphorus content of alfalfa and that small applications are just as effective as large ones.

TABLE 3.—*The effect of liming the soil on the phosphorus content of leaves of alfalfa grown in the field on Isabella sandy loam.*

Ground limestone per acre, lbs.	Number of comparisons	Increase in percentage P_2O_5 due to lime	Student's odds
552	20	−0.123*	5999:1
2,000	20	−0.117	832:1
6,000	20	−0.117	1916:1
12,500	20	−0.149	2499:1

*Decrease shown as negative increase.

The data on which Table 3 is based were taken from "Effects of Soil Type and Soil Treatments on the Chemical Composition of Alfalfa Plants" by A. L. Grizzard in this JOURNAL Vol. 27, pages 81–99). The same is true of the data in Table 4, and portions of that in Tables 5 and 6.

EFFECT OF APPLICATION OF SUPERPHOSPHATE TO MONTCALM SANDY LOAM ON PHOSPHORUS CONTENT OF GREENHOUSE-GROWN ALFALFA

From the data in Table 4 it is seen that of the three rates of superphosphate application only the two heaviest significantly raised the

phosphorus content of alfalfa hay. The third and fourth cuttings, moreover, seemed influenced more by the treatments than the first two. No effect on plant composition was observed from lighter phosphate application (data not shown). Definite conclusions should be avoided, however, in considering this table because the trials are so few in number that mathematical significance is doubtful. The figures are of value in that they show a tendency, but more definite statements are not justified by the data.

TABLE 4.—*The effect of the application of superphosphate to Montcalm sandy loam on the phosphorus content of greenhouse-grown alfalfa hay.*

Number of trials	Superphosphate per acre, lbs.	Increase in percentage P_2O_5			
		First and second cuttings		Third and fourth cuttings	
		Mean	S. D.	Mean	S. D.
3	1,200	-0.017	±0.0219	-0.027	±0.0548
3	2,400	0.017	±0.0145	0.103	±0.045
3	4,800	0.140	±0.0436	0.417	±0.0714

EFFECT OF SUPERPHOSPHATE FERTILIZATION ON PHOSPHORUS CONTENT OF FIELD-GROWN LEGUME HAY

The phosphorus content of alfalfa hay grown in the field was not significantly affected on either the heavy or the light soils by applications of superphosphate (Table 5). Statistical analysis of the data from one study showed that the phosphorus content of alfalfa leaves was very slightly increased by superphosphate applications. An increase of 0.02% was found with odds of 20:1 which is on the border line of significance. There is, then, a tendency towards an increase of phosphorus content through using superphosphate fertilizer.

TABLE 5.—*The effect of superphosphate fertilization on the phosphorus content of field-grown legume hays.*

Soil	Plant	Number of comparisons	Increase in percentage of P_2O_5	Student's odds
Heavy: Brookston, Miami, Kewanee, and Hillsdale..	Alfalfa hay	11	0.073	8:1
Light: Fox, Coloma, Plainfield, Rubicon, and Mancelona..................	Alfalfa hay	17	-0.029	4:1
Heavy: Brookston, Gilford, and Miami.............	Alfalfa leaves*	12	0.063	94:1
Light: Isabella............	Alfalfa leaves*	25	0.005	2:1
All soils..................	Red clover hay	5	0.150	211:1
All soils..................	Sweet clover hay	6	0.163	43:1

*See footnote to Table 3.

Red clover and sweet clover show a great response to superphosphate applications. The phosphorus content of the former was in-

creased 0.15% with odds of 211:1, which is highly significant. Sweet clover showed a similar increase. Here again, however, the number of samples taken is so small that the results are questionable. They can be safely interpreted only as tendencies.

EFFECT OF POTASH FERTILIZATION ON THE PHOSPHORUS CONTENT OF FIELD-GROWN LEGUME HAYS[5]

Potash applications did not greatly affect the phosphorus content of alfalfa hay (Table 6). The phosphorus content of the leaves of alfalfa grown on Isabella sandy loam was significantly decreased. In this connection it is interesting to note that potash usually increases the yield on this soil type.

The phosphorus content of red clover hay was not affected by potash application, but a significant decrease in the phosphorus content of sweet clover hay was noted.

TABLE 6.—*The effect of potash fertilization on the phosphorus content of field-grown legume hays.*

Soil	Plant	Number of comparisons	Increase in percentage of P_2O_5	Student's odds
Light: Fox, Coloma, Rubicon, Mancelona, and Plainfield	Alfalfa hay	11	-0.005	—
Heavy: Brookston, Miami, Hillsdale, and Kewanee	Alfalfa hay	10	0.017	2:1
Light: Isabella	Alfalfa leaves*	25	-0.074	506:1
Heavy: Brookston, Miami, and Gilford	Alfalfa leaves*	12	0.004	-
All soils	Red clover	7	0.001	—
All soils	Sweet clover	9	-0.092	138:1

*See footnote to Table 3.

SUMMARY AND CONCLUSIONS

A statistical study of the effect of fertilization on plant composition and of the interrelationships of nutrient elements in alfalfa, sweet clover, and red clover hay, based on analyses of these plants accumulated during a 13-year period, warrants the following conclusions:

1. Nitrogen and phosphorus contents correlated closely.
2. Nitrogen-potassium, potassium-phosphorus, magnesium-phosphorus, and magnesium-nitrogen contents all showed positive relationships.
3. Calcium-phosphorus, nitrogen-calcium, calcium-magnesium, and calcium-potassium contents all showed inverse relationships.
4. The phosphorus content of alfalfa hay grown on heavy soils was higher than that of hay grown on light soils.

[5]A review of literature on the effect of various treatments on the phosphorus content of alfalfa may be found in "Effects of Soil Type and Soil Treatments on Chemical Composition of Alfalfa", by A. L. Grizzard, Jour. Amer. Soc. Agron., 27: p. 81–91. 1935.

5. Superphosphate applications did not change the phosphorus content of field-grown alfalfa hay.
6. Superphosphate fertilization showed a slight tendency to increase the phosphorus content of alfalfa leaves grown on light soil.
7. Large applications of superphosphate increased the phosphorus content of greenhouse-grown alfalfa hay.
8. The phosphorus content of field-grown red clover and sweet clover was increased by superphosphate fertilization.
9. Limestone applications reduced the phosphorus content of alfalfa.
10. Potash applications tended to increase the phosphorus content of alfalfa, did not effect the phosphorus content of red clover, and decreased the phosphorus content of sweet clover.

CORRELATION OF THE WORK OF THE EXPERIMENT STATION AND THE EXTENSION AGRONOMIST IN DEVELOPING A SOUND EXTENSION PROGRAM[1]

J. S. OWENS[2]

IN the Land-Grant College system the agricultural teacher came first. He soon learned that he had little to impart except the traditions and even the superstitions which were the only existing bases for farm practice. It is not surprising that these were soon found inadequate. A demand for a more satisfactory body of teaching material was created and, before many years, acts creating special facilities for research were passed. Then, as a rule, the teacher's time was divided between teaching and research. Research had not been developed very far before farmers started demanding a larger portion of the time of the worker who already had two distinct duties. Although off-the-campus duties were confined chiefly to a few institute lectures, mainly during the winter period, they did give a direct farmer contact and this was reflected in the type of project selected for study, carried on chiefly through field trials.

With the passage of the Smith-Lever Act in 1914, most of the specialists for extension work, and even some county agents, were selected from those engaged in research. These men were familiar with the research of their time and even had first-hand acquaintance with much of the material which they were going to carry to the farmers.

The research workers who were not enticed to the new and flourishing pastures had fewer and fewer contacts with farmers. The sciences which are basic to agronomy grew rapidly and the research agronomist became further removed from the problems which were confronting farmers.

What happened to the extension agronomist? As farmers placed more confidence in his work, they demanded more and more of his time. The movement to make extension extremely popular and to reach every farmer immediately brought about highly organized and time-consuming methods of "putting over" extension. It became increasingly difficult to conduct research projects on the side, to maintain habits of systematic study, and even to keep one eye on the research related closely to his problems. Even more serious embarrassments followed. Research became more closely related to the pure science, e. g., studies of inheritance replaced variety trials. Research developed in so many directions that the extension worker not only found insufficient time to read the more important papers but found technic and theory becoming increasingly difficult to master.

While no satisfactory data are available it seems certain that at present subject matter specialization for extension usually follows the commodity interests. The agronomist endeavors to interpret the infor-

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[1]Contribution from the Agronomy Department, Connecticut State College, Storrs, Conn. Also presented before the annual meeting of the Society held in Chicago, Ill., December 1 to 3, 1937. Received for publication March 3, 1938.

[2]Professor of Agronomy.

mation relating to a crop, including crop improvement, soil management and fertilization, and often pest control, and then carries out a program covering the entire group of problems. This plan usually involves the fewest difficulties in developing and in conducting extension work. However, this seems inadequate criteria for measuring the value of a system.

In a few instances, the division for extension follows more closely the natural divisions which are recognized in the sciences. For instance, all of the plant disease work is under the guidance of a pathologist and he pays little attention to the crop divisions but crosses all, if need be. This system means a higher degree of specialization and should result in a more careful analysis of the problems and a closer approach to perfection in their solution.

There are also many instances of individuals combining extension with research and even residence teaching. There are research workers doing much effective extension work without direct assistance from extension organizations. The situation at a nearby substation merits description. The station is located near the center of a localized, high-value, cash crop industry. The worker in charge was chosen not only because of his capacity for productive research but also because he was to win and maintain farmer interest in the institution. Within a short time after the research was started farmers recognized its value and, since then, farmers flock to the institution with their problems. The workers are thus permitted to keep a close acquaintance with farm problems and to render a high type of extension teaching with a minimum of organized effort. The genius of this situation is that the same person can remain both the scholar and the teacher. It is what he has that draws the farmers to him and it is the opportunity for research which keeps him growing along with the farmers' problems. This illustration shows essentially the situation which existed before the development of specialized extension. Unfortunately, wide use of such a plan is impractical but possibly some of its values could be secured by other means.

We will now try to examine the possibilities for closer correlation between research and extension agronomy. Any conceivable solution presumes that the extension specialists are chosen because of scholastic ability and accomplishment equivalent to that of the research workers, and that both have equal opportunity for maintaining acquaintance with their respective interests. Myers (5)[3] has pointed out that extension has developed so rapidly that it has been difficult to develop the personnel needed. He further concludes that the extension specialist should have an educational background equal to that of the resident teacher and research worker. The Land-Grant College survey of extension work reported by Crocheron (2) states that the caliber of men in extension is inadequate and that more money will be needed to secure "adequate men".

The difficulty of maintaining a satisfactory grasp of agronomic information has already been mentioned in this paper and has been commented upon by Owens (6). Mighell (4), in reporting a study of

[3]Figures in parenthesis refer to "Literature Cited", p. 518.

professional improvement among agricultural economists, shows only 17 Land-Grant institutions out of the 47 replying that had any positive sabbatical leave system and only 20 leaves granted among 557 staff members during the years 1933-36. Nine of the 20 were in two universities. Furthermore, in 6 of the 17 states where there is a sabbatical system, extension workers are not eligible. He believes the discrimination against extension is due to over-centralization of the organizations. He also adds, "This is unfortunate since the nature of extension work in economics is usually such as to lead to a superficial grasp of problems unless one has opportunity for concentration not possible when actively engaged in routine affairs."

It is generally conceded that resident teachers need two to four months a year for physical recuperation and to reinforce their teaching material. Few extension workers have such opportunities. In addition, it has been considered good policy for teachers in agriculture to conduct some research, partially as a means of scholastic refreshment. Shinn (7), in reporting for a committee on instruction in agriculture in the Land-Grant colleges, states that in two colleges 100% of the teachers in agriculture give some of their time to research; in two others 90% or more do research and; among the 41 institutions reporting, 85.4% give some time to research. No similar information is available concerning the extent to which extension agronomists engage in research, but it undoubtedly would be much less.

The foregoing statements about sabbatical leaves and opportunities for research are given only to show that these means for professional improvement have not been so widely recognized as necessary for extension as for the other types of work. As a consequence, the extension worker may be handicapped in keeping pace with his colleagues.

The second fundamental for correlating the work in research and extension would seem to be a mutual understanding of the difficulties involved in the two types of work. Coffey (1) has analyzed this problem in some detail and suggests there should be some projects in the experiment station which in the course of completion call for cooperation with the extension forces. Myers (5) suggests that the remedy for research workers who do not appreciate extension is to go out and attempt to put across a piece of extension work. There appears to be an increasing recognition of the advantages in locating the extension specialist with the subject matter department. This affords frequent association which makes for understanding and appreciation.

With the assumption of good professional equipment and mutual appreciation, let us examine the possibilities for developing programs and conducting extension work.

For the first illustration, assume a hypothetical situation in an eastern state where dairying is important. Feed costs are high, whether purchased or grown on the farm, and yet there is an abundance of land which appears to be potentially good for pasture production. The farmer knows he is having trouble but cannot see the solution. Known methods for economic pasture improvement offer little hope to the extension worker. The research organization becomes interested and starts miscellaneous trials in an effort to determine what studies may become productive. The investigations lead on and

on. Finally, those who have conducted the investigations acquire knowledge and experience which give them an unusual understanding of pasture problems. Would it be possible to give the farmers a direct contact with these pasture experts and their enthusiasm—a product developed with the evolving pasture problem? They might be directly responsible for outlining the pasture program; yet, unless the research were projected into the variety of soil and climatic conditions and the many systems of management necessary on individual farms throughout the state, even the best application of the station findings would fall down.

Somewhere in this picture there must be a crossing of what is usually thought of as extension and as research. The extension specialist might enter as soon as the investigations show real promise. He might start supplementary experiments (no less scientific but probably less elaborate than those conducted at the station) to determine the modifications needed for practical use. This experience would give him an understanding which he would not get as a by-stander. Another choice would be for the station worker to conduct the supplementary experiments and thus remove the one limitation he would have for taking the extension load.

For the next illustration assume that there are several crops involved, including even some in the horticultural group. All of these are nearly alike with respect to the basic problems in nutrition and soil management, in improvement through breeding and selection, in disease and insect control. Each of these is now a highly specialized and difficult field and no one can be expected to be thoroughly acquainted with all of them. We will assume that there are known possibilities for improvement of the wheat crop. The geneticist brings his contribution into the extension program, or if he hasn't any special information, initiates a search. The workers in nutrition, disease, and insect control follow the same procedure. The frequent objection to the system just outlined is that it is impractical to carry out. This statement needs further examination. Seldom, if ever, would the entire group be working intensively with the same problems at the same time. It does seem to correct several of the faults of those in more common use. It narrows the scope of scientific interest and may be the only alternative as problems grow in number and in complicity. The significance of the accomplishment over a period of years might more than offset the mechanical difficulties involved.

The foregoing have been approached mainly from the point of view of the subject matter problems; or that of the research worker who has a body of specific information which he wishes to see utilized. The extension specialist who is a good observer also gets valuable information out of the farmers' experiences. The farmer presents his problem to him and he immediately attempts to find, not the final answer, but one which is better than the farmer's. He may draw upon many sources and evolve a solution. It is impossible for his own or neighboring institutions to have specific information for all of the problems he confronts. He must interpret and adopt from all available sources and not "extend" research in the narrower sense. All of these situations would indicate that the extension specialist needs all of his time for extension.

On the other side is the fact which has been recognized widely that the research worker needs the type of farm acquaintance which the extension specialist gets to orient and stimulate him. It appears appropriate to ask how much research should be built about the "practical" or more immediate farm needs. Certain research projects may be so distantly related to farm practice that correlation with the extension program is futile.

For the analysis here it is expedient to divide research into two categories, service and basic. While these terms have some unsatisfactory connotations they will do for the imaginary separation. The service or applied research might be combined with extension and the responsibilities divided as the personnel and other local situations necessitate. This would bring research and extension together into the same programs instead of, as sometimes happens, creating two divergent ones. It would remove the perplexing problem about when research information should be turned over to the extension service. After McCue (3) secured numerous statements on this matter from station and extension directors and from scientific workers, he concluded that too little attention was paid to trying out information after the research worker believed he had solved the problem.

The establishment of basic principles through more fundamental research is more remote from extension. The field may be so highly specialized and the technic so skilled that the worker can give little thought to the immediate use of his developments. Yet, in Land-Grant institutions it would seem that even basic studies should generally be aimed at improving very practical situations. The extension specialist may see the problems which require the basic research and should have opportunity to present them when research programs are planned. The extension worker conceivably could also have a part in determining what the investigation might mean for farm practice.

Irrespective of institutional organization the agronomist who is in contact with farmers must have a comprehensive fund of agronomic knowledge, and not musty at that. Glancing through summaries and abstracts does not give sufficient acquaintance with the literature. It is impossible to read the large number of original papers, many of which are voluminous and without special value. There is urgent need for the agronomists' preparing a series of monographs which would bring together all of the significant contributions, including interpretations for each of the major problems in the plant and soil sciences on which notable accomplishments have been made.

This would not be an easy task. The American Society of Agronomy could draw up a plan and seek support for it. The topics would need careful selection and the best talent in the field enrolled or possibly drafted. A special fund would be needed to release men from their regular duties and thus afford ample opportunity to do the type of summarization and interpretation needed.

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SOIL CONSERVATION FROM A LAND-USE VIEWPOINT[1]

J. S. Cutler[2]

PROPER land use is essential to an adequate soil conservation program on agricultural lands, but soil conservation cannot be achieved through land use alone. Soil conservation in the broadest sense implies maintaining the productive capacity of the land over relatively long periods. To achieve soil conservation not only requires that land be used for the purpose for which it is best suited but also necessitates the adoption of such soil conservation practices as are required for each kind of land. In other words, soil conservation and land use are intimately related but not synonymous. An attempt will be made to discuss the various interrelationships between proper land use and adequate soil conservation.

SOIL CONSERVATION VERSUS SOIL DETERIORATION

Obviously, soil conservation is the opposite of soil deterioration, but in order fully to understand the problems involved in soil conservation, it is desirable to give attention to those processes or practices that result in soil deterioration.

Reduction in mineral nutrients.—Throughout various sections of the United States, minerals are being removed continuously from the surface soil through leaching and crop removal. Obviously the reduction of mineral constituents of the soil is more rapid in a cash-grain farming than in a livestock farming system. This continual drain of the mineral nutrients from the soil necessitates the use of various fertilizers and liming materials.

Decline in organic matter.—Organic matter in the soil increases most rapidly under a grass cover. The plowing and tilling operations in the production of cultivated crops result in a continuous and fairly rapid reduction in the organic matter content of the soil. The growing of a large proportion of cultivated crops in relation to sod crops accelerates this reduction. Changing the crop rotation to bring about a better balance between the sod, or soil conserving crops, and the cultivated or soil depleting crops retards the decline. Bradfield[3] has shown that 40 years' cropping on Nappanee soil in Paulding County, Ohio, has increased the weight of soil per cubic foot, in the first foot from 65.5 pounds (in virgin soil) to 81.7 pounds. The pore space, expressed as percentage of the total volume, has declined from 60.3% to 50.5%. The organic matter content has declined from 132,000 pounds per acre in the virgin soil to 89,400 pounds in the soil cropped for 40 years. The lengthening of the crop rotation by including more years of meadow or rotation pasture results in the land being plowed and

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Dayton, Ohio. Also presented at Summer Meeting, Corn Belt Section, American Society of Agronomy, June 1937. Received for publication March 7, 1938.

[2]Regional Conservator, Region 3.

[3]Bradfield, Richard. Our heritage, the soil. Ohio State Univ. Agr. Ext. Serv. Bul. 175. 1936.

worked less frequently, thus retarding the rapid downward trend in organic matter content.

Impairment of physical condition of the soil.—To achieve good tilth, attention must be given to the moisture content of the soil at the time it is plowed or during the preparation of the seedbed. Working the heavier soils when they are too wet is likely to result in disastrous effects to the physical condition of the soil. Observations in northwestern Ohio point very definitely to a cumulative impairment of physical condition as a result of working the soil when too wet.

Erosion.—Recently erosion has been recognized as a most significant soil-deteriorating process. Under many conditions it has a greater effect on the productive capacity of the soil than all other deteriorating processes combined.

Recent studies of erosion on the long-time fertility plats at the Ohio Agricultural Experiment Station show considerable soil losses. By carefully measuring the depth of the soil horizons and the distance from the surface and comparing these measurements with uneroded soils, it has been possible to estimate in a systematic way the amount of soil lost by erosion.

Estimates[4] on plats cropped continuously in corn since 1894 on land with a slope ranging from 2 to 4% show an average soil loss of about 8.9 inches. Over most of this section of plats the B horizon has been turned up in plowing, indicating that at least two-thirds of the surface soil (A horizon) has been washed away. It is evident that the plow soil of today is quite different from that of 40 years ago. On the continuous oats plats, it is estimated that the soil loss for the section as a whole is 5.2 inches. The estimates for the annual average soil losses are 35 tons per acre per year for corn and 19 tons per acre per year for oats.

These studies of erosion on long-time fertility plats are of especial interest, since they agree closely with the results obtained more recently by the Soil Conservation experiment stations and serve to increase confidence in the results which these stations have obtained in the short period since their establishment. The National Resources Board[5] reports that erosion and leaching combined are responsible for 85.6% of the annual losses of plant food elements from the soils of crop and pasture areas of the United States. Of this loss 65% is from crop land and 20.6% from pasture. Grazing animals and harvested crops account for the removal of only 14.4% of the nitrogen, phosphorus, potash, calcium, magnesium, and sulfur lost annually.

LAND USE AS APPLIED TO AGRICULTURAL LANDS

From a land-use viewpoint, agricultural lands can be classified conveniently into crop lands, grasslands, and woodlands and are here defined as follows:

Crop lands.—Crop lands are lands regularly used for the production of cultivated crops, including rotation meadows and pastures, which at some time or other in the rotation are used for cultivated crops.

[4]CONREY, and BURRAGE. Erosion losses of soil from soil fertility plats. Ohio Agr. Exp. Sta. Bul. 561. 1936.

[5]National Resources Board Report. December 1, 1934.

Grasslands.—Under grassland is included permanent pasture or that which continues in grass for periods in excess of 5 years. Permanent meadows are also included—in other words, land which is not used for cultivated crops but only for the production of grasses and legumes either as pasture or hay.

Woodlands.—Woodlands include those lands utilized for the growing of trees and shrubs and the production of forest products.

FACTORS INFLUENCING LAND USE

In determining proper land use, such factors as soil, slope, erosion, cover, and field location, as well as certain economic factors, must be considered.

Soils.—Soils vary considerably in their native fertility and in their physical structure, factors which are expressed by the soil type. The physical structure of the soil affects its natural crop adaptations, ability to resist erosion, and ease of tillage. The native fertility of the soil determines to a large extent its productive level, as does also the manner in which the soil type responds to applications of fertilizer or liming materials. Obviously, many of the soil characteristics are interrelated as far as their effect on land use is concerned. Generally speaking, soils with a high productive level favor both plant root and top growth, and this greater growth in turn assists in the prevention of soil erosion through the increased binding effects upon the soil.

Slope.—The slope of the land largely determines the practicability of cultivation. Erosion losses are greater on steep slopes and drainage difficulties are increased with lack of slope. The length of the slope largely determines volume of run-off water. Experience has shown that certain slopes can be used for the production of cultivated crops, provided soil conservation practices are followed, while other steeper slopes are suited only for meadow or pasture and still others only for woodland.

Degree of erosion.—The present condition of the soil so far as erosion is concerned must be considered in determining proper land use. Degree of erosion is usually expressed in terms of the amount of topsoil that has been removed. Generally speaking, the productive capacity of any given field will vary directly with the depth of the surface soil. Thus, the amount of soil remaining in a given field provides a rough indication of the crop-producing power of the particular soil or soils.

Gullies may make cultivation impracticable and may thereby alter land use. The depth, width, and cross section of the gullies and their frequency determine the degree to which they will impede cultivation. Obviously, the more serious the gullying the greater the improvement costs will be if such lands are to be used for the production of crops or grasses. Hence, it is desirable that badly gullied lands be used permanently for woodland.

Plant cover.—The present cover of a given tract of land must be taken into account in land-use planning. In many parts of Region 3 relatively level lands are used for woodlands and crops are grown on sloping lands. From a long-time point of view it is desirable that these

more level lands be utilized, where possible, for crop production and that the steeper lands, already more eroded, be used permanently for woodland. Such a change must, of course, be accomplished gradually. If a land owner depends on products from his woodlands, it is highly essential that the steeper, eroded lands be reforested and given time to develop into productive woodlands before the present woodlands are cleared for crop production.

Present field location.—From a practical standpoint, many fields are not now located so as to permit the best use of land. Usually the length of the field determines the direction of the major cultural operations, no attention being paid to actual topography in the field. Too many fields throughout the Corn Belt show the disastrous effects of cultivation practiced up and down the slope. Originally many fields were laid out parallel to the line fences rather than with respect to topography, and no thought was given to soil conservation. There is ample evidence to show that "square" farming is not suited to a "round" country.

Economic factors.—The nature and location of markets, in part determine land use. Usually dairying is centered around major cities. Special local markets may make it desirable to produce special crops. Fruit and truck crops frequently are grown on lands not especially adapted to these crops, but their nearness to market makes such use fairly profitable.

In the poorer parts of Region 3 the necessity for economic returns from the land frequently causes some of the poorer farm lands to be put to uses to which they are not primarily suited. Under these conditions, yields are usually low. Some owners are so concerned in making a living that they cannot consider the effect of such misuse of land on the future productive capacity of the agricultural lands of this nation. A few farms have been found that have no land suited for field crop production. Here the land should be devoted entirely to grass and tree crops if the soil is to be preserved. However, the present owners require a certain acreage of cultivated crops and this results in improper land use.

RELATION OF SOIL CONSERVATION AND LAND USE

With respect to soil and slope certain lands may be suited, for example, to grass but the soil on these lands will be lost, even under appropriate land use, unless soil conservation practices such as liming and contour furrowing are followed. We might, for example, prepare recommendations of land use based on present farming methods. The areas suited to crops would be located largely on level lands, but these level lands are now showing marked evidence of deterioration through unwise cropping practices. It is essential that we adopt all known soil conservation practices and measures.

Recently the Soil Conservation Service estimated the acreage of the agricultural lands suitable for the production of cultivated crops in each state in this region. For example, in Kentucky, the census shows a total of 6,873,500 acres now in cultivation. Of this acreage only 1,598,800 acres, or 23.3%, is suitable for cultivation without satisfactory erosion control practices. In addition, it is estimated that

there are 487,600 acres now in pasture that are suitable for cultivation and 251,600 acres in brush or timber that might be cleared and utilized for tillable crops. In other words, a total of only 2,338,400 acres are actually suitable for cultivated crops under the present erosion-inducing cropping practices.

If, however, the best known soil conservation practices are followed, 5,234,100 acres, or 76.1% of the acreage now in cultivation, could be satisfactorily used for tillable crops in rotation. To this may be added the acres now in pasture and woodland suitable for cultivation under the best known soil conservation practices, making a total of 8,757,700 acres potentially tillable, or 1,884,200 acres more than are now in cultivation. To utilize this potentially tillable acreage requires not only proper land use, but the adoption and continuation of the best known soil conservation practices. These data are summarized in Table 1.

TABLE 1.—*Acreages of agricultural lands in Kentucky and Ohio suitable for the production of cultivated crops.*

Present status of land	Acreage reported in 1930 census	Land suitable for cultivation	
		Under present practices, acres	Under best soil conservation practices, acres
Kentucky			
Land now in cultivation	6,873,500	1,598,800	5,234,100
Land now in permanent pasture	6,740,782	487,600	2,708,900
Land now in brush or timber	5,421,246	251,600	814,700
Land in need of drainage	—	—	—
Ohio			
Land now in cultivation	10,690,035	6,827,120	11,697,020
Land now in permanent pasture	6,788,014	1,386,560	2,943,210
Land now in brush or timber	3,158,882	450,770	694,570
Land in need of drainage	—	12,740	12,740

To express the situation in another way, only 4 of the 120 counties in Kentucky have more than 25% of the land suitable for cultivation without erosion control, whereas in 71 counties only from 2 to 7% of the land is suitable, as shown in Table 2.

TABLE 2.—*Agricultural lands in Kentucky suitable for cultivation without erosion control.*

Percentage of land	Number of counties
2–7	71
7–15	37
15–25	8
Above 25	4

However, if the best known erosion-control practices are followed, an entirely different situation would prevail, as indicated in Table 3.

TABLE 3.—*Agricultural lands in Kentucky suitable for cultivation with erosion control.*

Percentage of land	Number of counties
0–15	34
15–34	32
35–50	28
50–69	20
70 and over	6

Studies in the other states in Region 3 show similar trends.

ACTUAL VERSUS IDEAL LAND USE

Studies of the actual and ideal land use have been made on the Salt Creek and Indian Creek projects in Ohio. Table 4 shows the distribution of the acreage of these projects with respect to the five slope classes and the actual and ideal percentages of the total area in crops and pasture.

TABLE 4.—*Actual and ideal land use for the Indian Creek (Ohio) and Salt Creek (Ohio) Soil Conservation Service demonstration projects.*

Slope	Percentage distribution of the entire area with respect to slope classes	Percentage of total area in			
		Cultivated crop		Pasture	
		Actual	Ideal	Actual	Ideal
	Indian Creek Project				
A (0-3%)	28.9	22.9	28.9	3.5	0.0
B (3-8%)	46.7	33.0	33.7	9.3	12.8
BB (8-15%)	9.7	5.9	0.0	2.8	9.5
C (15-25%)	6.7	0.7	0.0	3.4	0.0
D (over 25%)	8.0	0.0	0.0	3.3	0.0
Totals	100.0	62.5	62.6	22.3	22.3
	Salt Creek Project				
A (0-5%)	14.2	7.6	14.2	5.4	0.0
B (5-12%)	28.2	16.7	22.9	9.1	5.2
BB (12-20%)	26.6	10.0	0.0	13.2	26.6
C (20-30%)	12.5	2.4	0.0	7.4	10.6
D (over 30%)	18.5	0.0	0.0	6.5	0.0
Totals	100.0	36.7	37.1	41.6	42.4

This table shows that 26% of the total area in the Salt Creek project lies on BB slopes. Whereas, ideally, no part of this area should be under cultivation, a little less than one-third of all crop land on the project lies on BB slopes. On the other hand, 14.2% of the total lies on A slopes and whereas all of this land should be under cultivation, only about half of it is cultivated. The table shows that in both

projects crops are grown on all except the D slopes, whereas ideally only slopes A and B should be cultivated. Lands adapted to crop production are not utilized to the best advantage, particularly in the Salt Creek project.

Normally all B slopes require erosion-control measures if they are to be used for crop production; while on all the BB slopes, erosion-control measures are not only absolutely essential, but longer rotations must be followed if serious soil losses are to be prevented. If it were possible to rearrange the crop lands of the Salt Creek project so that the more level lands were used for cultivated crops even in this hilly area of eastern Muskingum County, Ohio, no slope of more than 12% would need to be used for cultivation. Such a rearrangement would provide an adequate acreage of cultivated crops for the system of livestock farming now being followed. The same general situation exists with respect to the lands now devoted to pasture. Many pastures are now located on lands which are primarily adapted to forest. Under ideal use, 37.1% of the land would be devoted to cultivated crops, 42.4% to pasture, and 20.5% to forest. It is well recognized that this ideal land use cannot be accomplished, but experience shows that by careful analysis and thoughtful planning in the rearrangement of each individual farm much can be done to approach the ideal.

An analysis of land use on Indian Creek Soil Conservation project in Butler County, Ohio, shows that no slope over 8% would need to be cultivated as there is sufficient acreage of A and B slopes (0–8%) for the present acreage of cultivated crops.

The soil conservationist's problem is to adapt the land classification and specific soil-saving practices to the individual farm. No preconceived formula can be applied directly. The general considerations must be analyzed and adapted to the peculiarities of the farm, as a tailor takes yard goods and cuts it to fit the shape of the customer.

READJUSTING LAND USE ON THE INDIVIDUAL FARM

In attempting to readjust land use on an individual farm the first step is to determine whether the present fields are properly located or properly divided and whether relocations will bring about better land use. In the field or portion of the field under consideration certain physical characteristics of the land or plants growing upon it will be helpful in determining whether the field is being used correctly. Are there many so-called "galled-spots" or "clay-spots"? These usually indicate that erosion has removed a large proportion of the surface soil from these areas. Is the field laid out in such a way that the farming operations are on the contour or at least at right angles to the general slope direction?

In grasslands, does the topography permit the application of fertilizer and liming material with machinery and clipping with a mower? Is the depth of the soil to underlying rock so shallow that grasses tend to "burn out" during the summer months? What is the quality of the farm woods? Frequently wooded areas have been so heavily grazed and burned that they do not have an understory of young seedlings and young trees. Where the tree stands cannot readily be thick-

ened and the ground surface is already covered by grass, it may be desirable to remove the existing trees and devote the area to pasture. Other areas, through the prevention of fire and grazing will improve so as to make vigorously productive woodland in a relatively few years. If the situation in the entire farm has been thoroughly analyzed, by fields or parts of fields, a proper land-use plan for the particular farm may be formulated.

The need for pasture, crops, and woodland products on each farm is the second consideration. These needs will vary with the type of farming practiced, but the studies made thus far indicate that there is a minimum acreage desirable for each of these general classes on every well-planned farm. A study of the farms on the Leatherwood Creek Soil Conservation project, Bedford, Indiana, at the time of the initiation of operations in 1935 showed that the average acreage used per animal unit of livestock kept was 1.2 acres of feed grain, ½ acre of hay, and 2.4 acres pasture (excluding woods pasture). Acreages required for most efficient feeding of this livestock were estimated to be 0.8 acre of grain, 1.2 acres of hay, and 3.5 acres of average pasture. This contrast between present acreages and acreages required to meet efficient feeding needs, based on most recent experimental evidence, indicates that most livestock farmers entering into a long-time soil conservation program must adjust their feeding practices if feed supplies and livestock needs are to be brought into balance.

A specific example of the relationship between land use and feeding practice is found in experimental work conducted by the Trumbull County, Ohio, Experiment Station[6] recently. A ration of heavy hay-light silage was compared with heavy silage-light hay feeding. A high quality alfalfa-timothy mixture hay was fed. Translated into acreages, the heavy hay-light silage ration required approximately ½ acre of corn, or its equivalent, for each acre of hay. The high silage-low hay ration required approximately 1.9 acres of corn for every acre of hay. In the first case 33% of the land would be in depleting crops and 67% in conserving crops, while in the second case 67% would be in depleting crops and 33% in conserving crops in order to provide the feeds required. The effect upon soil conservation is obvious. In addition the return above feed costs was distinctly in favor of the heavy hay-light silage ration. The cow, the soil, and the pocketbook profited from heavy feeding of high quality hay.

Since it is generally recognized that it is more difficult to maintain a satisfactory soil conservation program under a cash-grain farming system than under a livestock system, a grain farming system should not be practiced on the more sloping lands. The increased difficulty of working some of the more level heavier lands has forced the inclusion of legumes in the crop rotation, with the result that the corn, corn, oats plan of grain farming is disappearing.

The third step is to determine those shifts in land use that are both feasible and practicable. Usually it will be found that certain adjustments either in field boundaries, row direction, or in present use, can be made immediately to bring about a better land-use program. Also

[6] MONROE, C. F., and ALLEN, HAROLD. Increased hay feeding for dairy cows. Ohio Agr. Exp. Sta. Bul. 538. 1934.

such a farm analysis provides a basis for future land-use readjustments.

After the land use has been determined, the adoption of better farming methods should be considered. Obviously the goal is to obtain a maximum production with minimum loss of soil and soil nutrients and at a reasonable production cost. This means the adoption and use of balanced crop rotations adjusted to the soil and slope of each field, including a good legume or legume-grass meadow. Certain erosion-control practices, such as contour strip cropping and terracing, must be followed on the crop lands. This may require adequate applications of fertilizer and lime. Pasture land should be contour furrowed to conserve moisture and reduce run-off. Such other measures as are necessary to control weeds must be used. In management of woodlands, careful attention must be paid to protecting them from fire and grazing and in following the selection method of cutting. These practices illustrate some of the problems in land-use readjustment on the individual farm.

THE EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON NITROGEN FIXATION[1]

W. B. ANDREWS AND MARVIN GIEGER[2]

LEGUMES and nonlegumes have been grown together in pastures and in cultivated fields for a long time. The value of the associative growth of legumes and nonlegumes was recognized by Lyon and Bizzell (9),[3] whose data show that the growth of alfalfa with timothy increased the protein content of the timothy.

Virtanen (12, 13, 14, 15) and his co-workers established the reason for the nonlegume being benefited by the presence of the legume. They found that as much as 54 to 74% of the nitrogen fixed by the nodule bacteria on peas was excreted into the media in which the peas were growing and that barley took up 16 to 27% of the excreted nitrogen. In extreme cases the potato plant took up 10 times as much nitrogen as the legume in association whose yield was reduced. The excreted nitrogen was found to be 50% 1-aspartic and the remainder "probably di-amino-acid (lysine)".

The effect of the ratio of legumes to nonlegumes has been investigated by Virtanen (12) and by Wilson and Wyss (17). In general, the yield of the legume is reduced if too many nonlegumes are grown with it. The excretion of nitrogen (14) has been found to be much greater in soil, sand, and Kaolin than in water media.

Virtanen (12) found that excretion of nitrogen takes place with red clover, white clover, and peas when good strains of bacteria were used. In addition to the presence of alfalfa increasing the protein content of timothy, Lyon and Bizzell (9) obtained similar results with timothy and oats when clover and peas, respectively, were grown with them. The results of Lipman (7) are similar to those of Lyon and Bizzell. Thornton and Nicol (11) found that rye grass obtained considerable quantities of nitrogen from alfalfa when they were grown together.

Nonlegumes are not always benefited by the associative growth of a legume. Lipman (7) found that soybeans reduced the yield of corn. Ludwig and Allison (8) obtained depressed yields of nonlegumes when grown in the presence of cowpeas, alfalfa, vetch, and sweet peas. Bond (4) and Stallings (10) did not obtain a benefit to nonlegumes when they were grown in the presence of soybeans. However, in Wilson and Wyss' (17) experiments, 23 to 60% of the nitrogen fixed by Manchu soybeans was excreted.

In pasture experiments Johnstone-Wallace (5, 6) found that the growth of wild white clover with Kentucky bluegrass in pasture plats increased the yield of the grass from 881 to 2,243 pounds per acre and the protein content from 18 to 25%.

Wilson and Burton (16) and Wilson and Wyss (17) have investigated the factors affecting the excretion of nitrogen by legumes. The former present a good review of the literature on the subject, showing that excretion of nitrogen by leguminous plants takes place in many cases and that often the yield and protein content of nonlegumes grown with legumes is increased to a marked degree.

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[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication March 7, 1938.
[2]Associate Agronomist and Chemist, respectively.
[3]Figures in parenthesis refer to "Literature Cited", p. 536.

In the winter of 1931–32 greenhouse experiments were set up to determine the effect of the association of rye and Austrian winter peas and of nitrate of soda on nitrogen fixation.

EXPERIMENTAL

Austrian winter peas and rye were grown alone and together in 3-gallon earthenware pots. Twenty-five pounds of sandy loam soil were put into each pot. Seeds were planted in separate containers on November 18 and transplanted December 1, 1931. There were twice as many rye plants as Austrian winter pea plants in the pots. The pots containing both Austrian winter peas and rye contained the same number of rye plants and the same number of pea plants as when they were grown separately.

Nitrate of soda was applied at 0, 50, 100, 200, 400, and 800 pounds per acre. The nitrate of soda was applied in divided applications at approximately 2-week intervals until March 7.

The Austrian winter peas were inoculated with a good strain of nodule bacteria. An 0–8–4 fertilizer was applied to the soil in each pot at the rate of 2,400 pounds per acre.

The plants were harvested the first part of April at which time the Austrian winter peas were blooming. The smallest rye was in the bloom stage and the largest rye had not commenced to bloom.

In harvesting, the tops were removed just above the level of the ground and the soil was thoroughly wetted. The roots were then worked out of the soil after which they were washed as free of soil as convenient in clean water. As reported in a previous paper (3), where soybean roots are concerned, it is practically impossible to remove the soil from the roots to a uniform degree. The yield and percentage of nitrogen of the roots are therefore reported with a uniform ash content of 8%. The yield and percentage of nitrogen data of the tops are reported on the air-dry basis.

Nitrogen determinations were made on the soil at the beginning and at the end of the experiment. The nitrogen determinations were made according to the official methods.

In presenting the data the yields, percentage of nitrogen, total nitrogen, and amount of nitrogen fixed are presented for each treatment. To determine the effect of the association of rye and Austrian winter peas, the data were paired according to nitrogen treatment and averages and average differences were calculated. Student's odds for significance were used with the paired data. There were 19 pairs of data in these cases.

RESULTS AND DISCUSSION

EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON YIELD OF AUSTRIAN WINTER PEAS AND RYE

The 400- and 800-pound rates of nitrate of soda reduced the yield of Austrian winter pea tops and roots significantly when grown alone (Table 1). The yield of the roots was 6.9 ± 0.59 grams per pot without nitrogen treatment and 3.8 ± 0.59 grams per pot with 800 pounds of nitrate of soda per acre. Intermediate rates of nitrate of soda produced intermediate reductions in root growth. Even though the higher quantities of nitrate of soda reduced the yield of the peas when

grown with rye, the differences are not statistically significant. Each increase in nitrate of soda applied increased the yield of the rye tops when grown alone and when grown with Austrian winter peas. The higher quantities of nitrate of soda reduced the yield of roots when rye was grown alone.

TABLE 1.—*Effect of association of rye and Austrian winter peas and of nitrate of soda on yield of Austrian winter peas and rye in grams per pot.*

Pounds $NaNO_3$ per acre	Austrian winter peas, grams	Rye, grams	Roots, grams	Total, grams
		Austrian Winter Peas Grown Alone		
None	68±5.8‡	——	6.9±0.59	75±5.8§
50*	54±3.8	——	5.3±1.25	59±4.0
100	59±5.6	——	5.8±1.33	65±5.8
200	75±5.2	——	4.0±0.64	79±5.2
400†	52	——	3.5	56
800*	45±5.1	——	3.8±0.59	49±5.1
		Austrian Winter Peas and Rye Grown Together		
None	54±9.1	12±0.4	15.0±2.98	81±9.6
50*	62±3.8	13±1.0	13.2±0.89	88±4.0
100	49±6.8	16±1.1	11.7±1.95	77±7.2
200*	53±3.4	19±1.5	12.2±1.01	84±3.9
400	45±7.7	28±3.6	10.9±0.15	84±8.5
800*	43±7.8	29±0.8	9.1±1.58	81±8.0
		Rye Grown Alone		
None	——	16±1.3	6.7±0.55	23±1.4
50	——	17±1.0	7.4±0.55	24±1.1
100	——	23±1.6	12.7±1.92	36±2.5
200	——	27±1.5	9.8±1.47	37±2.1
400	——	33±2.4	12.6±1.53	46±2.9
800	——	50±0.4	12.2±1.65	62±0.5

*Average of three pots instead of four.
†Average of two pots instead of four.
‡Standard error
§The standard error of the total equals the square root of the sum of the squares of the standard errors of the figures added.

The yield of tops and roots of Austrian winter peas and rye grown together (Tables 1 and 5) was greater in every case than either grown alone. The yield of peas alone was 66 grams per pot and of peas and rye 83 grams per pot, the difference in favor of growing them together being 17 grams per pot. Austrian winter pea tops were 7 grams per pot less when grown with rye than when grown alone. The peas reduced the yield of the rye 8 grams per pot. These differences are significant statistically.

EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON NITROGEN CONTENT OF AUSTRIAN WINTER PEAS AND RYE[4]

Increasing the nitrate of soda applied had a tendency to decrease the percentage of nitrogen in Austrian Winter peas when grown alone

[4]Part of the rye obtained in this experiment was used to determine the effect of the nitrogen content of rye on its rate of decomposition. This was reported in a previous paper (2).

and when grown with rye (Table 2). In general, increasing the nitrate of soda increased the percentage of nitrogen in the rye. When rye was grown alone, it had 0.77% nitrogen and 1.29% where none and 800 pounds of nitrate of soda were applied. Where peas were grown with rye, the corresponding percentages of nitrogen were 1.14 and 1.29%, respectively.

TABLE 2.—*Effect of the association of rye and Austrian winter peas and of nitrate of soda on the nitrogen content of Austrian winter peas and rye.*

Pounds $NaNO_3$ per acre	Percentage nitrogen in		
	Austrian winter peas	Rye	Roots
	Austrian Winter Peas Grown Alone		
None	2.49±0.183‡	——	3.98±0.196
50*	2.34±0.347	——	4.18±0.466
100	2.33±0.236	——	3.87±0.135
200	2.41±0.145	——	4.21±0.335
400†	2.45	——	3.10
800*	2.33±0.155	——	3.15†
	Austrian Winter Peas and Rye Grown Together		
None	2.86±0.070	1.14±0.060	2.91±0.193
50*	2.72±0.057	1.25±0.047	3.62±0.191
100	2.65±0.075	1.36±0.069	3.12±0.083
200*	2.94±0.101	1.21±0.097	3.22±0.080
400	2.43±0.143	1.40±0.070	2.68±0.187
800*	2.64±0.223	1.69±0.096	3.03±0.388
	Rye Grown Alone		
None	——	0.77±0.057	1.10±0.191
50	——	0.82±0.067	1.36±0.115
100	——	0.79±0.040	0.93±0.104
200	——	0.90±0.069	1.21±0.031
400	——	1.21±0.047	1.21±0.113
800	——	1.29±0.016	1.28±0.018

*Average of three pots instead of four.
†Average of two pots instead of four.
‡Standard error

With only one exception the percentage of nitrogen in the rye tops was increased due to the presence of the peas. The average increase was 0.41% which is very highly significant (Table 5). The nitrogen content of Austrian winter peas was increased 0.35% due to the presence of the rye. The increase in nitrogen content of Austrian winter peas due to the presence of rye has not been found in the literature with any legume.

EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON TOTAL NITROGEN IN AUSTRIAN WINTER PEAS AND RYE

The data reported above show that the growth of rye and Austrian winter peas together reduced the yield of tops of both slightly and increased the percentage of nitrogen in both significantly. When the yield and nitrogen content are combined to give total nitrogen

(Tables 3 and 5), the Austrian winter peas grown alone and with rye contained considerably less nitrogen when the higher rates of nitrate of soda were applied. The total nitrogen in rye was increased with each increase in nitrate of soda applied.

TABLE 3.—*Effect of association of rye and Austrian winter peas and of nitrate of soda on the total nitrogen in Austrian winter peas and rye in grams per pot.*

Pounds $NaNO_3$ per acre	Austrian winter peas, grams	Rye, grams	Roots, grams	Total, grams
		Austrian Winter Peas Grown Alone		
None	1.70±0.259‡	————	0.23±0.019	1.93±0.260§
50*	1.29±0.256	————	0.20±0.032	1.49±0.258
100	1.42±0.281	————	0.19±0.041	1.61±0.284
200	1.84±0.238	————	0.14±0.026	1.98±0.239
400†	1.28	————	0.10	1.38
800*	1.08±0.210	————	0.11±0.032	1.19±0.212
		Austrian Winter Peas and Rye Grown Together		
None	1.55±0.026	0.15±0.016	0.36±0.057	2.06±0.065
50*	1.69±0.161	0.17±0.018	0.40±0.040	2.29±0.167
100	1.29±0.181	0.22±0.025	0.24±0.131	1.75±0.225
200*	1.57±0.055	0.23±0.004	0.33±0.038	2.15±0.067
400	1.13±0.255	0.38±0.041	0.25±0.035	1.76±0.261
800*	1.14±0.061	0.49±0.030	0.23±0.052	1.90±0.086
		Rye Grown Alone		
None	————	0.12±0.006	0.06±0.000	0.18±0.006
50	————	0.14±0.005	0.10±0.000	0.24±0.005
100	————	0.18±0.011	0.09±0.000	0.27±0.011
200	————	0.24±0.011	0.10±0.018	0.34±0.021
400	————	0.37±0.005	0.13±0.012	0.50±0.013
800	————	0.65±0.032	0.13±0.023	0.78±0.041

*Average of three pots instead of four.
†Average of two pots instead of four.
‡Standard error.
§The standard error of the total equals the square root of the sum of the squares of the standard errors of the figures added.
*Standard error.

The growth of rye with Austrian winter peas tended to offset the reduction in total nitrogen produced by nitrate of soda on Austrian winter peas and, as a result, the total nitrogen in the peas and rye grown together did not vary as did that where the peas were grown alone. The total nitrogen was 1.66, 1.99, and 0.37 grams per pot where peas, peas and rye, and, rye, respectively, were grown (Table 5). The rye and peas had 0.33 gram of nitrogen more per pot than peas grown alone which is highly significant. The increased nitrogen in the peas and rye was practically equal to that in the rye grown alone.

The Austrian winter pea tops had practically the same total nitrogen when grown alone and when grown with rye even though the presence of the rye reduced the yield. Similarly, the lower yield of rye obtained in the presence of the peas contained about the same total nitrogen.

EFFECT OF ASSOCIATION OF RYE AND AUSTRIAN WINTER PEAS AND OF NITRATE OF SODA ON NITROGEN FIXATION

The percentage of nitrogen in each of three different samples of the soil at the beginning of the experiment was 0.0250 and that at the end of the experiment 0.0260 ± 0.00080, 0.0256 ± 0.00072, and 0.0255 ± 0.00052 (average of 22 determinations) where rye, Austrian winter peas, and Austrian winter peas and rye, respectively, were grown. On the basis of these data it is concluded that the crops had an insignificant influence upon the nitrogen content of the soil. The nitrogen fixed was obtained by subtracting the nitrogen added in nitrate of soda from that contained in the plants. The nitrogen in the seed was not taken into consideration. The Austrian winter pea and rye seed contained approximately 0.02 gram and 0.003 gram of nitrogen per pot, respectively. These data are reported in Tables 4 and 5.

TABLE 4.—*Effect of association of rye and Austrian winter peas and of nitrate of soda on nitrogen fixation in grams per pot.*

Nitrogen in plants, grams	Nitrogen added in $NaNO_3$, grams	Nitrogen fixed, grams
	Austrian Winter Peas Grown Alone	
1.93±0.260*	0.00	1.93
1.49±0.258†	0.05	1.44
1.61±0.284	0.09	1.52
1.98±0.239	0.18	1.80
1.38‡	0.37	1.01
1.19±0.212†	0.74	0.35
	Austrian Winter Peas and Rye Grown Together	
2.06±0.065	0.00	2.06
2.29±0.167†	0.05	2.24
1.75±0.225	0.09	1.66
2.15±0.067†	0.18	1.97
1.76±0.261	0.37	1.39
1.90±0.086†	0.74	1.16
	Rye Grown Alone	
0.18±0.006	0.00	0.18
0.24±0.005	0.05	0.19
0.27±0.011	0.09	0.18
0.34±0.021	0.18	0.16
0.50±0.013	0.37	0.13
0.78±0.041	0.74	0.04

*Standard error.
†Average of three pots instead of four.
‡Average of two pots instead of four.

The application of nitrate of soda in high amounts reduced the nitrogen fixed where Austrian winter peas, peas and rye, and rye were grown. The nitrogen fixed was 1.44, 1.77, and 0.15 grams per pot where Austrian winter peas, peas and rye, and rye were grown, respectively. The growth of rye with peas increased the nitrogen fixed 0.33 gram per pot which is highly significant.

The growth of rye with Austrian winter peas increased the nitrogen fixed in every case. Where 800 pounds of nitrate of soda were applied, the rye increased the nitrogen fixed from 0.35 to 1.16 grams per pot.

TABLE 5.—*Summary of the reciprocal effect of the association of rye with Austrian winter peas, average of 19 pots.*

Crop	Yield, grams per pot	Percentage nitrogen	Total nitrogen, grams per pot	Nitrogen fixed, grams per pot
	Whole Plants			
Austrian winter peas	66.4	2.44	1.66	1.44
Austrian winter peas and rye	82.6	2.40	1.99	1.77
Rye	36.2	0.94	0.37	0.15
Increase due to presence of rye	16.2	−0.04	0.33	0.33
Odds (Student)	4999	2	232	249
	Tops			
Austrian winter peas grown alone	59.0	2.39	1.43	—
Austrian winter peas grown with rye	51.9	2.74	1.48	—
Increase due to rye	−7.1	0.35	—	—
Odds (Student)	98	1393	—	—
Rye grown alone	26.3	0.94	0.27	—
Rye grown with Austrian winter peas	18.5	1.35	0.25	—
Increase due to presence of peas	−7.8	0.41	—	—
Odds (Student)	9999	9999	—	—

SUMMARY

Austrian winter peas and rye were grown separately and together in the greenhouse in 3-gallon pots. Nitrate of soda was applied at the rates of 0, 50, 100, 200, 400, and 800 pounds per acre. The yield and nitrogen content of the tops and roots were determined. The following conclusions were drawn:

1. The application of nitrate of soda in large amounts reduced the yield and nitrogen content of Austrian winter peas when grown alone and when grown with rye.
2. The application of nitrate of soda increased the yield and nitrogen content of the rye in proportion to the amount of nitrate of soda applied.
3. The yield of Austrian winter pea tops was reduced slightly by the growth of rye with the peas.
4. The yield of rye grown with Austrian winter peas was almost as large as that of rye grown alone when small amounts of nitrate of soda were applied and considerably less when high amounts of nitrate of soda were applied.
5. The combined yield of Austrian winter peas and rye grown together was considerably greater than that of Austrian winter peas grown alone.
6. The percentage of nitrogen in the combined Austrian winter peas and rye grown together was not significantly less than that of Austrian winter peas grown alone.
7. The growth of rye with Austrian winter peas increased the average nitrogen content of the peas from 2.39 to 2.74%.
8. The growth of Austrian winter peas with rye increased the average nitrogen content of the rye from 0.94 to 1.35%.

9. The total nitrogen in the Austrian winter peas and rye was 0.33 gram per pot greater than where peas were grown alone.

10. The application of nitrate of soda reduced the nitrogen fixed where Austrian winter peas, Austrian winter peas and rye, and rye were grown.

11. The growth of rye with Austrian winter peas increased the nitrogen fixed from 1.44 grams per pot where peas were grown alone to 1.77 grams per pot where they were grown together.

12. The rye and the Austrian winter pea tops each contained practically the same quantity of nitrogen when grown together as each had when grown separately.

13. The growth of rye with Austrian winter peas increased the nitrogen fixed by an amount almost as large as the quantity of nitrogen in the rye, i. e., 0.33 and 0.37 gram per pot, respectively.

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NOTES

TWO IMPROVED NURSERY THRESHERS[1]

THE recent inclusion of light-seeded grasses and legumes in varietal experiments at Pullman, Wash., has created a demand for better threshing equipment at this station. In an attempt to meet these needs a toothed-cylinder type of nursery thresher and a small roller-belt thresher have been constructed. The cylinder thresher is an improved model of one previously described.[2]

THE TOOTHED-CYLINDER THRESHER

The toothed-cylinder nursery thresher was designed to thresh a wide range of crop plants and to separate the seeds or fruits from the other plant parts rather completely or at least sufficiently to facilitate subsequent recleaning. A sketch of this machine is shown in Fig. 1, and photographs of the two sides are shown in Fig. 2. The principal features of the machine are as follows:

1. Over-shot cylinder, with hinged concave unit that is raised easily without stopping the machine, and which rises automatically when a foreign object gets caught in the cylinder accidentally, thus avoiding excessive damage to the teeth.
2. Beater with blades which practically stops the rebounding of grain out of the end of the short shaker, and which partly regulates the flow of material onto the shaker.
3. Short screenless shaker which carries the threshed material into the air stream.
4. Air blast cleaning system which usually cleans wheat, oats, peas, etc., sufficiently to permit the recording of yield weights without recleaning.
5. Sacking device to replace the grain pans for seeds that roll or slide easily.
6. Self-cleaning of internal parts.
7. Hinged feed board supported by a spring so as to be raised easily for cleaning.
8. Automatically controlled damper in feed chute to prevent seed from spitting back from the cylinder.
9. V-belts and assorted pulleys to permit the varying of the relative speeds of the cylinder and other moving parts.
10. Adjusting screws to level the machine on uneven floors (not used when the thresher is mounted on the trailer).
11. Recleaner attachment, consisting of a ¼-inch mesh screen-bottomed box and a fan to permit the recleaning of one sample while another is being threshed.

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[1]Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Division of Agronomy, State College of Washington, and the Pacific Northwest Soil Conservation Experiment Station. Published as Scientific Paper No. 385, College of Agriculture and Experiment Station, State College of Washington.

[2]VOGEL, O. A., and JOHNSON, ARTHUR. A new type nursery thresher. Jour. Amer. Soc. Agron., 26:629–630. 1934.

A 1½ h. p. air-cooled, self-oiled gasoline engine has proved to be a satisfactory source of power for most nursery samples.

For separating the stems from the fruits of alfalfa, red clover, and many grasses that have stems heavier than those of the fruits, a long-

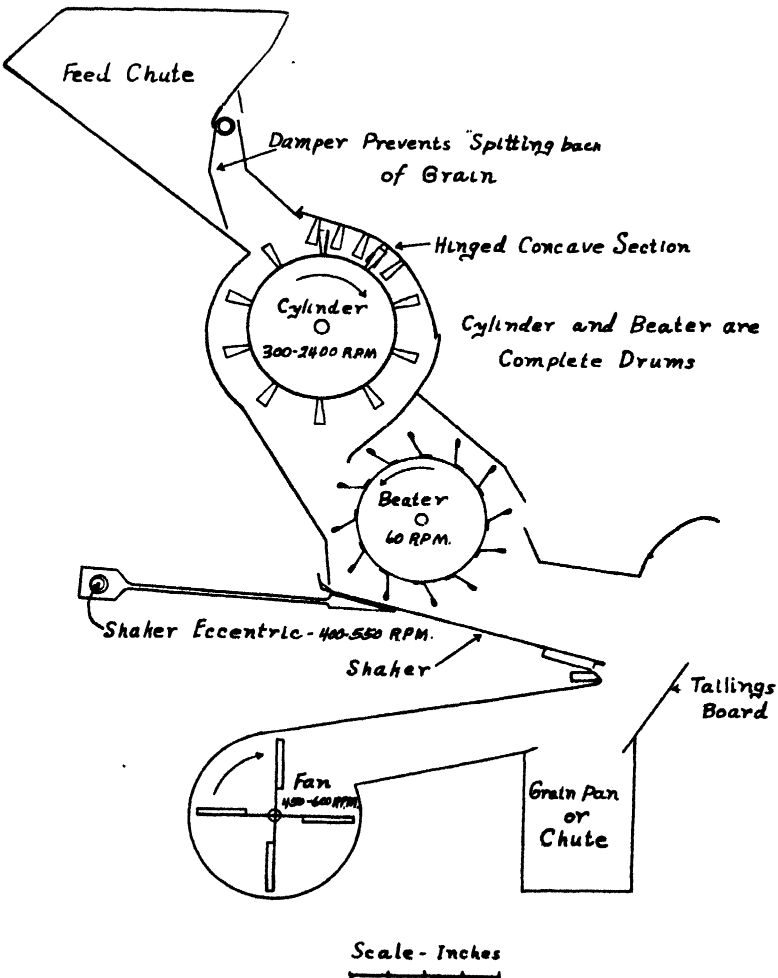

FIG. 1.—Working principle of the toothed-cylinder thresher.

toothed comb with ¼-inch spaces between the teeth is attached to the end of the shaker. This carries the stems over the end of the tailings board but allows the fruits to fall between the teeth into the pan. The comb functions satisfactorily because the stems are deposited on the shaker by the beater blades at right angles to the teeth of the comb.

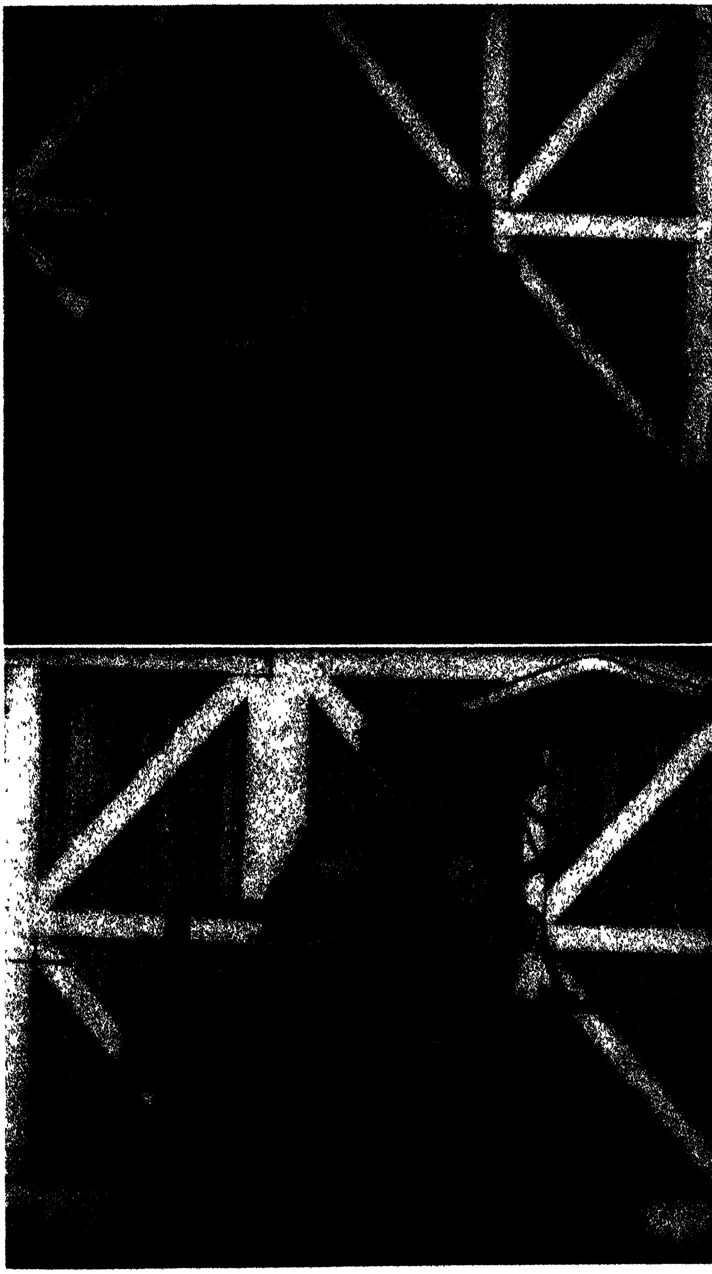

FIG. 2.—Two views of the toothed-cylinder thresher.

If so desired, a screen can be attached to the end of the shaker where it can be easily watched and cleaned.

The use of the thresher here described has reduced the cost of threshing and cleaning nursery samples of small grains during the past two years to a fraction of that required when inadequate equipment only was available. The thresher is towed to the nursery and set in a convenient location and the bundles, which are never wrapped, are carried to the thresher. The rate of threshing bundles containing 1 to 4 pounds of grain to be kept pure is approximately three to four per minute. Small bundles for pure seed containing not over 1 pound of grain, or larger bundles threshed only for yield, often are threshed at the rate of 300 to 325 per hour.

The entire bundle often is passed through the machine when the straw is less than 24 inches in length, but the butts of longer bundles usually are withdrawn. Bundles of small grain wrapped in paper and shipped to the station by cooperators are threshed without removing the paper as the latter does not interfere with threshing.

Samples of barley having some of the beards and hoods attached to the seed after threshing usually are set aside and rethreshed later with the cylinder speed reduced to avoid cracking the grain.

Sometimes a few partially threshed wheat heads remain in the threshed grain. These heads are later caught on the recleaner screen and are threshed quickly by rubbing them against the screen.

ROLLER-BELT THRESHER

The roller-belt thresher has been constructed so recently that it has not been tested so thoroughly as the toothed-cylinder thresher. It is designed primarily for small samples and is self-cleaning. As shown in Fig. 3, this machine operates on the very simple principle of a rough-surfaced roller rubbing against a slower moving rough-surfaced belt.

The belt, a 13-inch piece of hydraulic hose, 10 inches in diameter, and woven from 20-strand cotton cord, has a very rough surface. The wearing quality of the belt was increased by water-proofing with Lumino.

The three large rollers are made of wood and are 13 inches long and approximately 4 inches in diameter. A 13-inch piece of hydraulic hose, 4 inches in diameter and made of 20-strand cord, was slipped over the rubbing roller and fastened securely at the ends with sodium silicate (water glass). This hose was almost saturated with shellac to harden the fabric and increase its wearing quality.

A more wear-resisting corrugated or rough covering for the rubbing roller no doubt could be made of ⅛-inch round steel welding rods placed side by side lengthwise of the roller and fastened to the surface of the wood cylinder with glue or sodium silicate. The rods should be welded or soldered together at the ends so as to render the resulting "cylinder" more able to withstand rough use.

The frame to which the two belt rollers are attached is suspended from the shaft of the upper roller, thereby leaving the lower end swinging freely. By moving the free end of the roller base toward the rubbing roller the pressure of the belt against the rubbing roller is

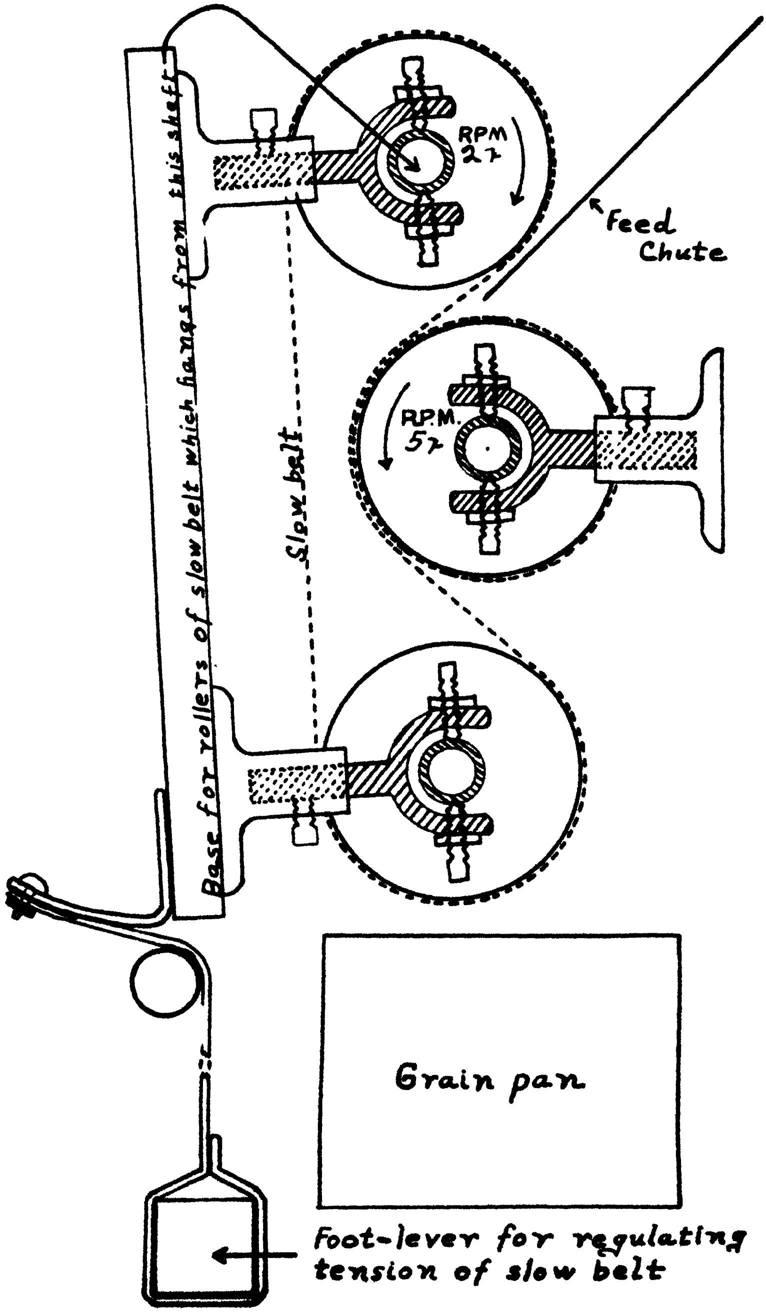

FIG. 3.—Working principle of the roller-belt thresher.

increased. This pressure is regulated at will by means of a foot-lever. The amount of rubbing surface is regulated by increasing or decreasing the distance between the belt rollers, thereby tightening or loosening the belt.

Photographs of two views of this thresher are shown in Fig. 4. The frame of one side of the machine was constructed so that in threshing the plant butts can be held to one side of the rollers to simplify the threshing and cleaning operations.

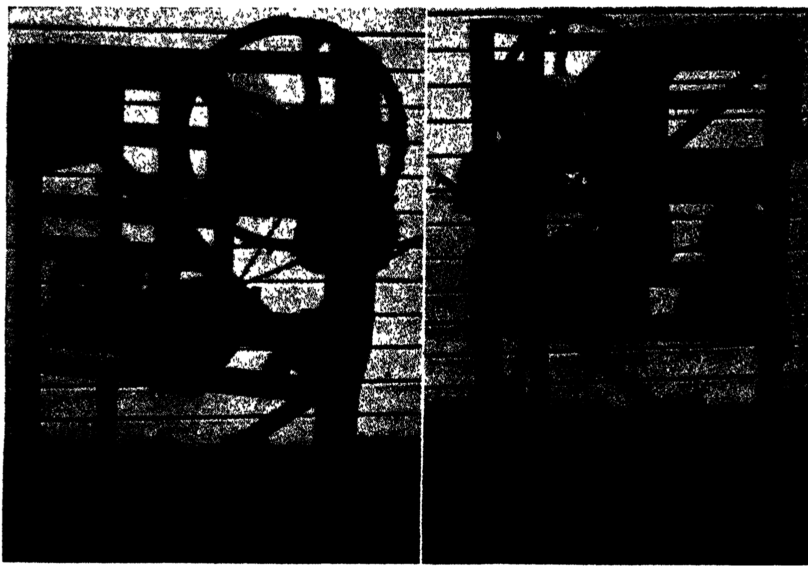

FIG. 4.—Two views of the roller-belt thresher.

A short roller was placed in a diagonal position between the two belt rollers to serve as a guide and to prevent the belt from traveling too far toward the sprocket side of the rollers.

Materials that have been threshed satisfactorily include heads and plants of wheat, oats, barley, flax, rice, sweet sorghum, and a number of grasses. The machine has been used to hull sweet clover, red clover, sainfoin, and alfalfa that was threshed with the toothed-cylinder thresher.

Large samples of alfalfa having too many pieces of hard stems were threshed more easily with another thresher consisting of a corrugated metal drum and an ordinary 12-mesh window screen which operates by a principle similar to that of the roller-belt thresher except that the screen is stationary but is easily removed for cleaning. A 16-mesh screen can be used for red clover with surprisingly good results. Either of these rubbing threshers can be run by a 1/3 h. p. electric motor.—O. A. VOGEL, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture;* WILFORD HERMANN, *Division of Agronomy, Washington Agricultural Experiment Station;* and LOY M. NAFFZIGER, *Pacific Northwest Soil Conservation Experiment Station, U. S. D. A., Pullman, Wash.*

DETERMINING THE EFFECTIVENESS OF COMMERCIAL CULTURES OF NODULE-FORMING BACTERIA ON THE YIELD OF PINK BEANS (*Phaseolus vulgaris*), BLACKEYE BEANS (*Vigna sinensis*), AND WILBUR BEANS (*Phaseolus lunatus*)[1]

THE gathering of nitrogen from the air in leguminous plants through the symbiotic relations between the host and bacteria (*Bacillus radicicola*) in nodules appearing on their roots has long been well established. It has been found that specific forms of these bacteria are necessary for nodule formation in each legume host. Several commercial preparations are found on the market to supply these specific forms where the legume host fails to form nodules, or even where the prevailing forms in a soil fail to give satisfactory performance. From time to time some of these commercial preparations of bacterial cultures have been tested in California. The behavior of three of these cultures is here reported.

In 1937 plats were sown at Davis with seed of pink beans (*Phaseolus vulgaris*), Blackeyes (*Vigna sinensis*), and Wilburs (*P. lunatus*). These beans represent the common varieties grown in California. Each was carefully inoculated with the specific bacterial culture designed for it, according to the directions accompanying the culture. The Wilbur and Blackeye beans were planted in double rows 300 feet long and spaced 30 inches apart, and the Pink beans on June 23 to avoid the effect of heat which causes blossoms of this variety to drop when planted earlier. The stands and set of seed were all satisfactory, without insect or disease damage of any sort. No difference in the appearance of the plants or seed could be detected when contrasted with the untreated similarly spaced checks which were in adjacent rows. At harvest yields were secured as reported in Table 1.

TABLE 1.—*Yields in pounds of seed per acre of treated and untreated beans at Davis, Calif., 1937.*

Variety	No. of plats	Check plats, pounds per acre	Treated plats, pounds per acre	Difference in yield, pounds per acre	Standard error, pounds per acre	Odds of significance*
Blackeye .	10	1,560	1,562	2	21	1.17 : 1
Wilbur....	10	1,875	1,888	13	49	1.86 : 1
Pink.	20	1,161	1,228	67	58	6.61 : 1

*Data analyzed by Student's method.

The differences in yield between treated and untreated checks for each variety of beans is shown not to be significant. Even for the Pink bean, which shows the most favorable yield, the increase in yield compared with the standard error is so small that for practical purposes it has no significance.

It must be concluded, therefore, that the Yolo silt loam at Davis, California, is well supplied with nodule-forming bacteria, fully as effective as those supplied by the commercial concern for the varieties of the three species of beans tested.

The Yolo series of soils includes the best and the most extensive bean soils in California and appears everywhere to possess an abundant flora of the necessary *Bacillus radicicola* for the beans under test. It has been found, however, that the specific forms required for causing nodules on garvanzo (*Cicer arietinum*) and on *Melilotus coerulea* have been absent in the years during which these legumes were under test.—W. W. MACKIE, *California Agricultural Experiment Station, Berkeley, California.*

BOOK REVIEWS

PLANT ECOLOGY

By John E. Weaver and Frederic E. Clements. New York: McGraw-Hill Book Co., Inc. Ed. 2. XXII + 601. Pages, illus. 1938. $5.

THE second edition of this book which received so much favorable comment on its first appearance has been pretty completely revised in the light of the advances made in ecological work in the past decade. Evidence of the thoroughness may be noted in the bibliography which listed 601 entries in the first edition and which now contains 1,035 entries despite the fact that a considerable number of the older references have been dropped. This bibliography is an item of outstanding importance in this reviewer's opinion, and adds tremendously to an already extremely valuable book.

The text has been rewritten in many parts and has been reorganized in others. Over 60 pages of additional matter are incorporated into the text aside from the increased bibliography and index. Some of the illustrations have been replaced by better examples; a few have been added; and the location shown has been noted on the legends of a number which acquire more value from the added definiteness.

The chapter on Methods of Studying Vegetation has been enlarged considerably (16 pages) by addition of material on basal area, clip, frequency-abundance, and pantography-chart quadrats, isolation transects, relict method, pollen analysis, etc. The chapter on Units of Vegetation has been enlarged and further subdivided. These examples will illustrate the amount of revision. An effort has been made to emphasize the relation of ecological studies to conservation of natural resources.

To summarize briefly, the authors have included much recent data, corrected many of the weaknesses of the first edition, and have increased the value of the text very considerably. (G. P. VE.)

REPORT OF THE FOURTH INTERNATIONAL GRASSLAND CONGRESS

Edited by R. O. White. Aberystwyth, Wales: Imp. Bur. Plant Genetics. 486 pages. 1937. £2.

THE volume is introduced with the presidential address by Professor R. G. Stapledon, pioneer pasture research worker, followed

with reports of business meetings and papers of members and friends of the Congress. The papers are divided into seven sections as follows: Plenary papers; grassland ecology, range management, and physiology; seed mixtures; plant breeding, genetics, and seed production; nutritive value of pastures and fodder conservation; pasture management and economics; and methods of obtaining yield determinations. Because of the large number of pasture research workers from many countries and varied climatic conditions, the reports are difficult to review.

This brief report on this volume of data is not indicative of its value to those interested in pasture research. The report should be widely accepted because grassland problems are disclosed from numerous scientific angles. Research workers should review these data.

A smaller volume with abstracts in English and German is available for five shillings, post free. (R. E. B.)

AN INTRODUCTION TO SOIL SCIENCE

By Benjamin Isgur. Boston: Agricultural Scientific Publishing Co. 239 pages. 1938. $2.50.

THIS book is arranged primarily for students in a two-year course in agriculture. The subject matter discussed is not exhaustibly portrayed, but rather the essential factors are related and much that is required to substantiate the subject matter left to the instructor's lectures. Only the relatively simple phenomena are taken up. The chapters noted are historical, some elements of chemistry, the origin of the earth, the rock-soil cycle, soil formations, soil separates and soil classification, soil texture and soil structure, tillage and tillage implements, soil surveys, plant nutrition and composition, organic matter and micro-organisms, soil acidity and lime, soil moisture, drainage and drainage systems, crop rotation, fertilizers, and soil diagnosis.

The book contains material serviceable for laboratory exercises. (W. S. E.)

AGRONOMIC AFFAIRS

METHODS OF APPLYING FERTILIZER

UNDER the above heading, the National Joint Committee on Fertilizer Application has published recommendations covering methods of fertilizing various crops as prepared by a special committee appointed at the thirteenth annual meeting of the Joint Committee in Chicago in November 1937. The recommendations were reviewed prior to publication by members of the Joint Committee and suggestions and corrections embodied in the published report.

The publication is a 16-page pamphlet with illustrations and includes a summary of recommendations for cotton, corn, tobacco, potatoes, snap beans, lima beans, peas, kale and salad greens, spinach, field beans, sweet potatoes, sugar beets, and small grains. A brief discussion of fertilizer distributing machinery is also included.

The report was published by the National Fertilizer Association and copies may be procured upon request to H. R. Smalley, General Secretary of the Joint Committee, 616 Investment Building, Washington, D. C.

NOTICE CONCERNING THE PROGRAM FOR THE 1938 MEETING OF THE CROPS SECTION

ALL members of the Society desiring to offer papers on the program of the Crops Section in Washington next fall are requested to communicate as soon as possible with the Chairman of the particular Sub-section in which the paper belongs, as indicated below. Dr. Ide P. Trotter, Chairman of the Crops Section, and other members of the Program Committee are desirous of completing the program by September 1. The Sub-sections and the Sub-section chairmen are as follows:

Sub-section I. Breeding, Genetics, and Cytology. Dr. R. J. Garber, Director, U. S. Regional Pasture Research Laboratory, State College, Pa.

Sub-section II. Physiology, including Nutrition, Morphology, and Taxonomy. Dr. F. D. Keim, Department of Agronomy, University of Nebraska, Lincoln, Nebr.

Sub-section III. Miscellaneous Crops Papers not Covered by Sub-sections I and II. Dr. Ide P. Trotter, Department of Agronomy, Texas A. & M. College, College Station, Texas.

Arrangements may also be made for conferences by small groups on special topics for inclusion in Sub-section III, but advance notice should be given the Program Committee as such conferences should be included in the printed program. If a meeting place for the conference is to be provided by the Committee, information to that effect should also be included in the notice to Dr. Trotter.

NEWS ITEMS

THE ANNUAL meeting of the Canadian Seed Growers Association was held at the Ontario Agricultural College at Guelph June 15 to 17.

THE IMPERIAL Bureau of Pastures and Forage Crops at Aberystwyth, Great Britain, has published as Bulletin No. 25 of its Herbage Publication Series a report on "Erosion and Soil Conservation". It includes a compilation of recent literature on soil conservation and gives attention to the degree and extent of erosion, the causes of erosion, and erosion control measures as practiced in the different parts of the world. The material is arranged according to countries and their political subdivisions, including the Mediterranean region, U.S.S.R., the East Indies, the West Indies, China, Japan, Africa, the United States, Canada, Australia, and Fiji.

DR. A. E. ALDOUS, Professor of Agronomy and specialist in pasture management of Kansas State Agricultural College, died suddenly on May 5 at the age of 51.

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FLOWERING AND POD SETTING IN GRAM, *CICER ARIETINUM*, L.[1]

B. S. KADAM, R. K. KULKARNI, AND S. M. PATEL[2]

GRAM, *Cicer arietinum*, L., is an important staple pulse crop in India, occuping annually over 14,000,000 acres. In the Bombay Presidency, gram stands foremost among the pulses, occupying over 750,000 acres annually.

The improvement of this important crop was taken up in 1933 at the newly opened Cereal Breeding Station at Kundewadi, Niphad, Nasik District. Along with the plant breeding investigations agronomic and botanical studies were also undertaken. This paper presents observations on flowering and fruiting in gram.

REVIEW OF LITERATURE

Howard, *et al.* (2)[3] observed that flowers open from 9 a.m. and close the same day before sunset. As a rule they open again next morning between 8:30 and 11 a.m. and close finally late in the afternoon. The length of time a flower remained open varied from 7 to 15 hours. These workers further observed that the lowest buds open first and that flowering follows a cymose arrangement. The anthers dehisce and pollination occurs in the bud stage insuring self-fertilization. Cloudy or rainy conditions are deterimental to setting of pods.

Ayyar and Balsubrahmanyan (3) found a considerable amount of cleistogamous flowers in a summer crop. The incidence of cleistogamy is considered to vary according to nutritional conditions of the soil. They found that most of the flowers that opened on the first day, as a rule, did not open on the second day. In the normal crop active blooming was between 9 and 10 a.m., while the summer crop bloomed mostly at 2 p.m. The second opening was earlier in the day than the first one. Dehiscence and pollination occurred a day before the opening of the flower.

The observations of Shaw and Khan (4) show that the incidence of sterility and of two-seeded pods are closely associated with yield and that both vary with the season.

[1]Contribution from the Section of the Crop Botanist to Government of Bombay. Published with the approval of the Director of Agriculture, B. P. Poona, India. Received for publication November 11, 1937.

[2]Crop Botanist to Government of Bombay and Graduate Assistants, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 557.

MATERIAL AND METHODS

Eighteen pure local types, the Local and an improved type, Nagpur-62, from the Central Provinces formed the material for the present studies.

Gram is usually sown by a three-coultered drill. In order to obtain uniform spacing and to facilitate observation, the seed was dibbled at a distance of 4 inches in rows 18 inches apart. Dibbling was done by a poker which made holes of uniform depth. Seed was deposited in the holes and covered with loose soil and pressed lightly.

In studying the relation of flowering and pod formation individual flowers were numbered and dated. Pods from each of these were harvested separately. In observing blooming, standards of flowers that had bloomed were clipped off slightly every day to distinguish them from fresh flowers. No detrimental effect of clipping of standards was observed. In all cases border plants were discarded.

RESULTS

FLOWERING

Flowering in individual plants.—In Table 1 is shown flowering of five individual plants of a typically early strain, G-693, and in Table 2 that of the five plants of a late strain, G-758. In each case the frequencies of the five plants have been added together and averages for each day are given.

It will be seen from Table 1 that in G-693 plants begin to flower as early as November 21, but that continuous blooming does not commence until a week later. At this time most of the branches have their buds fully developed so that the first flowers on most of the branches start simultaneous blooming. The tempo of blooming increases gradually and is in full swing for about two weeks, then a gradual decline sets in. The average maximum number of flowers per day in G-693 was 7.20, while an individual plant might have had as many as 10 flowers a day.

The flowering in G-758 (Table 2) commenced as early as November 23, but like the early strain G-693 it gained momentum after about a week. Plants continued flowering as late as December 26, 10 to 12 days later than G-693. The average number of maximum flowers was 4.60, while the highest number recorded was 11. On the whole, G-758 exhibited a lower amount of flowering than G-693.

Flowering in populations.—Twenty-five plants in 19 different pure types and in the Local were studied to ascertain the amount of flowering and pod formation. The data are summarized in Table 3.

It will be seen that the early types commenced blooming from 34 to 46 days after sowing and finished in from 67 to 70 days. In the mid-late types blooming commenced from 38 to 48 days after sowing and lasted from 27 to 37 days. The late and very late types did not differ much from the mid-late types.

Nagpur-62 was in a class by itself, commencing to flower very late and continuing for nearly a month and a half. It will be noted that the Local, although mid-late in maturity, showed as long a range as Nagpur-62.

There was evidently a good deal of variation in the total number of flowers per plant. It will be noted that, in general ,the early types possessed a minimum number of flowers per plant. The average number of flowers per plant was more or less the same in early, mid-late, and late types. The very late and extremely late strains showed much lower averages

TABLE 1.—*Blooming in five individual plants of the early strain G–693.*

Plant No.	November 1935									
	21	22	23	24	25	26	27	28	29	30
4	1	0	0	0	0	0	2	2	1	4
8	0	0	0	0	1	0	1	1	3	4
9	0	0	1	0	0	0	1	1	0	1
10	0	0	0	0	0	1	2	1	1	6
12	0	0	0	1	0	2	3	2	2	4
Total	1	0	1	1	1	3	9	7	7	19
Flowers per plant per day	0.2	0	0.2	0.2	0.2	0.6	1.8	1.4	1.4	3.8

	December 1935							
	1	2	3	4	5	6	7	8
4	5	4	4	4	4	5	5	5
8	5	6	6	9	6	8	5	4
9	1	1	2	5	2	3	4	1
10	6	4	7	8	6	4	7	2
12	5	1	3	3	3	4	6	3
Total	22	16	22	29	21	24	27	15
Flowers per plant per day	4.4	3.2	4.4	5.8	4.2	4.8	5.4	3.0

	December 1935							
	9	10	11	12	13	14	15	16
4	4	6	2	2	2	0	0	0
8	2	8	5	1	2	0	1	0
9	2	6	1	4	5	2	2	4
10	6	10	4	2	4	1	0	0
12	4	6	6	1	2	2	0	0
Total	18	36	18	10	15	5	3	4
Flowers per plant per day	3.6	7.2	3.6	2.0	3.0	1.0	0.6	0.8

Time of opening and closing.—During the season of 1934–35, opening and closing of flowers was observed in Nagpur-62 gram. On January 29, 1935, a number of buds were selected in the evening and observations recorded at hourly intervals the next day. The results are summarized in Table 4.

Of the 20 buds under observation, 11 opened on the first day and the remainder the next day. The opening of flowers on the first day was in the afternoon between 2:35 and 5:30. This was a cloudy day. All the buds closed between 6 and 6:30 p.m., immediately after sunset. These flowers re-opened on the second day (January 31, 1935) between 11:15 a.m. and 12:07 p.m. and remained fully opened until sunset, when all of them closed soon after. The interval between the first and second opening was from 18 to about 23 hours. Seven out of the 11 buds re-opened for the *third* time on February 1, 1935, between 10:15 and 10:46 a.m., the interval between the second and third opening being 22 to 23 hours.

TABLE 2.—*Blooming in five individual plants of the late strain G-758.*

Plant No.	November 1935							
	23	24	25	26	27	28	29	30
1	0	0	0	1	1	1	0	2
2	0	0	0	0	0	1	1	1
3	0	0	0	0	0	1	1	0
4	1	1	1	1	0	1	0	5
5	0	0	0	0	0	0	1	1
Total	1	1	1	2	1	4	3	9
Flowers per plant per day	0.2	0.2	0.2	0.4	0.2	0.8	0.6	1.8

	December 1935									
	1	2	3	4	5	6	7	8	9	10
1	1	2	2	2	4	1	4	3	5	5
2	0	1	2	2	0	2	2	2	2	3
3	1	1	2	1	1	1	2	0	1	1
4	4	4	4	3	5	1	4	4	4	11
5	1	1	1	3	1	2	3	3	2	3
Total	7	9	11	11	11	7	15	12	14	23
Flowers per plant per day	1.4	1.8	2 2	2.2	2.2	1.4	3.0	2.4	2.8	4.6

	December 1935							
	11	12	13	14	15	16	17	18
1	5	3	7	1	5	5	0	0
2	3	4	4	5	6	7	4	3
3	4	1	5	5	1	3	0	0
4	4	5	4	5	5	4	2	0
5	3	3	2	3	1	4	3	1
Total	19	16	22	19	18	23	9	4
Flowers per plant per day	3.8	3.2	4.4	3.8	3.6	4.6	1.8	0.8

	December 1935							
	19	20	21	22	23	24	25	26
1	0	0	0	0	0	0	0	0
2	4	1	5	1	3	0	0	2
3	1	2	0	0	0	0	0	0
4	3	1	2	0	0	0	0	0
5	3	1	4	3	1	1	2	4
Total	11	5	11	4	4	1	2	6
Flowers per plant per day	2.2	1.0	2.2	0.8	0.8	0.2	0.4	1.2

The buds which opened for the first time on January 31 between 11:29 a.m. and 2:32 p.m. re-opened for the second time only. No third opening of these flowers was observed. January 31 was a clear day.

TABLE 3.—*Summary of flowering and pod setting in 20 different types of gram during 1935–36.*

Type No.	Life period in days	Period of flowering from sowing in days	Maximum and minimum number of flowers per plant	Average number of flowers per plant	Average number of pods per plant	Percentage pod setting
1	2	3	4	5	6	7
			Early Types			
G-258	95	46-70	32-94	65.6	36.4	55.5
G-262	100	34-70	21-84	58.0	30.7	52.9
G-397	100	36-70	23-89	64.6	36.4	56.3
G-693	100	35-67	31-126	68.2	37.7	55.2
G-769	100	43-68	25-125	71.6	39.1	54.6
G-306	100	39-69	31-95	53.4	24.6	46.1
Averages..				63.57	34.15	53.43
Local .	103	36-80	25-123	68.7	32.2	46.8
			Mid-late Types			
G-248	103	44-76	20-116	67.0	35.5	53.0
G-412	103	45-80	8-97	62.9	33.9	53.9
G-421	103	38-75	33 100	65.8	34.4	52.2
G-494	103	46-75	5-125	68.6	37.9	55.2
G-705	103	48-75	11-144	77.4	41.4	53.5
Averages..				68 3	36.62	53.56
			Late Types			
G-130	107	39-78	17-111	75.7	29.4	38.8
G-339	107	48-75	50-150	87.1	44.1	50.6
G-531	107	42-73	15-187	87.2	36.6	41.9
G-758	107	43-80	19-90	61.0	27.4	44.9
G-434	107	41-74	23-79	46.0	22.1	48.0
Averages				71.40	31.92	44.84
			Very Late Types			
G-348	110	51-79	6-75	47.4	27.2	57.3
G-WF3	110	46-80	13-97	49.0	24.5	50.0
Averages				48.20	25.85	53.65
			Extremely Late Type			
Nagpur-62	130	52-95	10-86	42.4	23.3	54.9

It will be noticed that in the two sets of flowers those that opened on January 30 did so late in the afternoon, while the second lot flowered much earlier on January 31.

In order to observe blooming of flowers on a large scale a large number of unopened buds of G-262 were tagged in the season of 1935–36. The data are given in the Table 5.

All the 104 flowers that opened for the first time on November 27, 1935, closed that day after sunset. The next day all except 5 re-opened between 10 a.m. and 2 p.m., the bulk of the flowers opening in the

TABLE 4.—*Blooming of flowers in cloudy and clear weather during 1934–35.*

Bud No.	Cloudy day, Jan. 30, 1935, time of first opening	Partly cloudy day, Jan. 31, 1935		Interval between 1st and 2nd opening in hours	Clear day, Feb. 1, 1935		Interval between 2nd and 3rd opening in hours
		Time of first opening	Time of second opening		Time of second opening	Time of third opening	
1	—	12:03 p.m.	—	22:57	11:00 a.m.	—	—
2	5:30 p.m.	—	11:32 a.m.	18:02	—	10:46 a.m.	23:14
3	4:13 p.m.	—	12:04 p.m.	19:51	—	10:28 a.m.	22:24
4	5:22 p.m.	—	11:33 a.m.	18:11	—	—	—
5	—	2:32 p.m.	—	19:43	10:15 a.m.	—	—
6	2:35 p.m.	—	11:34 a.m.	20:59	—	10:15 a.m.	22:41
7	—	11:30 a.m.	—	22:45	10:15 a.m.	—	—
8	5:23 p.m.	—	12:05 p.m.	18:42	—	10:17 a.m.	22:12
9	—	11:29 a.m.	—	22:49	10:18 a.m.	—	—
10	3:03 p.m.	—	12:06 p.m.	21:03	—	—	—
11	—	12:06 p.m.	—	22:14	10:20 a.m.	—	—
12	—	12:30 p.m.	—	22:15	10:45 a.m.	—	—
13	4:41 p.m.	—	12:07 p.m.	19:26	—	—	—
14	—	11:35 a.m.	—	22:47	10:22 a.m.	—	—
15	5:11 p.m.	—	11:35 a.m.	18:24	—	10:23 a.m.	22:48
16	—	12:10 p.m.	—	22:53	11:03 a.m.	—	—
17	—	1:34 p.m.	—	22:00	11:34 a.m.	—	—
18	4:15 p.m.	—	11:25 a.m.	19:10	—	—	—
19	2:39 p.m.	—	11:20 a.m.	20:41	—	10:29 a.m.	23:09
20	4:10 p.m.	—	11:15 a.m.	19:05	—	10:27 a.m.	23:12

TABLE 5.—*Opening of flowers en masse in G–262 during 1935–36.*

Time	Nov. 27, 1935, No. of buds opening 1st time	Nov. 28, 1935		Nov. 29, 1935	
		No. of buds opening 2nd time	No. of buds closing	No. of buds opening 3rd time	No. of buds closing
9 a.m.	—	—	—	9	—
10 a.m.	—	12	—	2	—
11 a.m.	1	10	—	1	—
12 noon	22	63	—	2	—
1 p.m.	46	8	—	—	4
2 p.m.	10	6	—	—	2
3 p.m.	—	—	12	—	1
4 p.m.	6	—	2	—	4
5 p.m.	5	—	14	—	2
6 p.m.	14*	—	71	—	1
Total	104	99†	99	14	14

*Half open
†Five buds did not open the second time.

forenoon. All these closed from 3 p.m. to 6 p.m. on the same day, the majority closing at 6 p.m. On the third day 14 flowers re-opened for the third time. These were the 14 buds which had half opened on the first day.

Sequence of opening of flowers.—Each branch, whether tertiary or secondary, forms an entity and blooms independently of other branches. Flowering, therefore, goes on simultaneously in various branches and sub-branches. The basal flowers bloom first, followed by others in a cymose arrangement. The actual flowering is diagramatically illustrated in Fig. 1.

Cleistogamy.—No cleistogamous flowers were observed.

POD FORMATION

Amount of pod formation.—The incidence of pod setting was determined from averages obtained from the study of 25 plants in each type. The average number of flowers and pods per plant and the percentage of setting are given in the last three columns of Table 3.

The percentage of setting varied in early strains from 46.1 to 56.3 with a general average of 53.43. Although mid-late types showed a slightly higher average number of flowers per plant than the early types, the average setting of pods was about the same as in the earlier strains. The late types generally had a higher number of flowers per plant than the early and mid-late strains, but the pods formed per plant were fewer, resulting in lower setting. The very late types had a very low average number of flowers and pods. The setting, however, was as high as the early types. The Nagpur-62 strain showed the same behavior. The Local gram showed considerable low setting, although the average number of flowers per plant was the same as that of mid-late strains.

Although early types were somewhat lower in average number of flowers per plant than the late strains, the higher amount of setting

of the former made them considerably higher yielding. In order to ascertain this feature further correlation coefficients were calculated between the amount of flowering and pod setting and are given in Table 6.

TABLE 6.—*Correlation between number of flowers and number of pods in early and late strains of gram.*

Early strains	n	r	Late strains	n	r
G-258	25	0.9158	G-130	24	0.7979
G-262	25	0.8455	G-339	24	0.8134
G-397	25	0.8080	G-531	25	0.8605
G-693	25	0.9539	G-758	24	0.7845
G-769	24	0.9589	G-434	25	0.8923
G-306	25	0.8829	—	—	—
Average r	131	0.9070	Average r	107	0.8338

The theoretical values of correlation coefficients at 0.01 point for $n\text{-}2 = 22$ and 23 are 0.515 and 0.505. It will be seen that all the values are highly significant. The coefficients of early strains as a rule are larger than those of late strains. The estimated average values of r in the two groups are 0.9070 and 0.8338, respectively, the former being significantly larger.

Sterility.—A certain number of pods in a gram plant are without seed. Such pods are confined, usually, at the extremity of the branches (Fig. 1). Any flowers formed above the empty pods are shed, as a rule, Thus empty pods result from late-formed flowers. The incidence of sterility in early types varied during the two years, 1934–35 and 1935–36 from 5.3 to 12.5% in early and from 2.6 to 16.8% in late types. The incidence of sterility theretore is very variable from season to season.

Number of seeds in a pod.—The number of seeds per pod in the various strains was noted in 1934–35 and 1935–36. One-seeded pods formed the largest proportion, ranging from nearly 66 to 87%. In 1934–35 the proportion of two-seeded pods was much higher than in the following year. Three-seeded pods rarely occurred. There was considerable variation in the proportion of one- and two-seeded pods from season to season.

The two-seeded pods were usually located at the base of the branch, i.e., the first or the second flower at the base of the branch usually resulted in two-seeded pods (Fig. 1). In case the lower pods were damaged by insects the pods immediately above them usually developed two seeds. In the beginning a plant has few pods to nourish, hence, it is likely to develop both the ovules in a pod. This is probably the most likely reason of the location of two-seeded pods at the base of the branches.

Weight of seed in one- and two-seeded pods.—The combined weight of seeds in the two-seeded pods was more than the seed from one-seeded pods. Individually, however, the grains in the two-seeded pods weighed less than those from the one-seeded pods. One of the grains in the two-seeded pods was invariably heavier than its companion. In two-seeded pods the grains were adpressed and conse-

quently developed an irregular shape unlike the grains in one-seeded pods, which were round and well developed.

In a plant of strain G-693 the weights of seeds from one-seeded pods ranged from 0.102 to 0.163 gram, as compared with 0.105 to 0.130 gram of larger seeds from two-seeded pods.

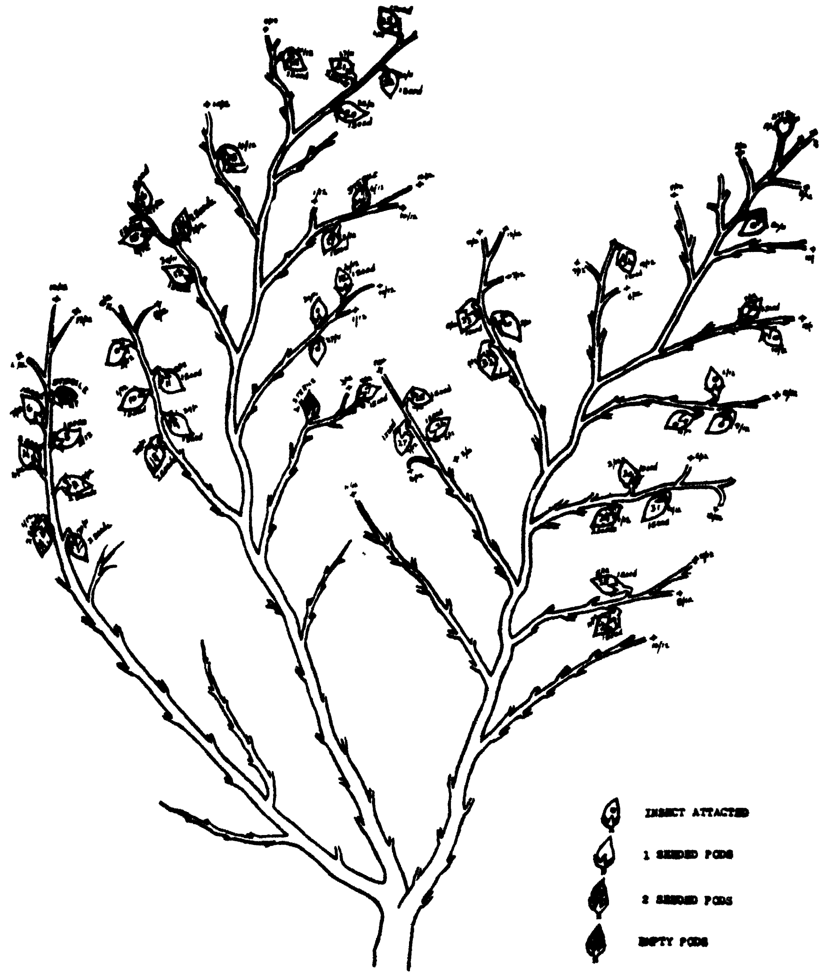

FIG. 1.—Graphic illustration of a gram plant showing dates of flowering, pod formation, and number of seeds per pod.

DISCUSSION

The period of daily blooming is longer at Niphad than at Pusa and Coimbatore as observed by the Howards and Khan (2) and by Ayyar and Balasubrahmanyan (3), respectively. The closing of flowers is also delayed at Niphad as compared to the time of closing at the other two places. The variations may either be due to inherent differences

in the material or to the climatic conditions obtaining at the various places. It is more likely that both factors may be operating.

In addition to the two successive openings of a flower as observed by the above workers, we also observed blooming for the third time. Such cases were associated with young buds which had not completely opened on the first day and in flowers whose initial opening was delayed until late in the afternoon due to cloudy weather. About 5% of the flowers opened only once. In this respect our observations are in accord with those of the Howards but differ from those of Ayyar and Balasubrahmanyan who recorded 78 to 85% such cases at Coimbatore. We did not observe any cleistogamous flowers, which occurrred in abundance at Coimbatore.

In early types more flowers manage to develop into pods than in the late types. The correlation coefficients between the amount of flowering and pod setting of early types were generally higher than those of late strains, the average value of r of the former being significantly larger than that of the late strains. Since there is not much difference in number of flowers, amount of sterility, and two-seeded pods, it appears that late types shed more flowers than early types. We have observed that late-formed flowers are usually shed, and since flowering of late strains continues a week or more beyond that of the early types, it follows that more shedding of flowers must be taking place in the late strains, with consequent reduction in pods.

The excessive shedding of flowers in late types appears to be related to soil moisture. The non-irrigated gram crop has to grow throughout its life period on the available soil moisture which progressively diminishes as the season advances. It has been observed that most of the earlier-formed flowers result in pods, while late-formed flowers have a considerably lower percentage of setting. Evidently, after a certain limit, the soil moisture begins to act as a limiting factor and its influence is greater on late strains whose flowering period parallels the lower moisture conditions of the soil.

Shaw and Khan (4) mention that pink-flowered types show larger percentages of two-seeded pods, suggesting a probable association of the two characters. The lowest amount of two-seeded pods in such types as mentioned by them was 31% and the highest 72%. In our material the strains under consideration were all pink flowered and none showed more than 29% of two-seeded pods.

SUMMARY

1. The average number of flowers blooming per day in an early type of gram was 7.20, while on an individual plant as many as 9 to 10 flowers may bloom on a day.

2. Blooming in a strain population continues from 3 to 5 weeks. The range of flowering is more or less the same in strains of different maturity periods. Early types begin to flower a week earlier than late ones.

3. Under Niphad conditions early, mid-late, and late types have more or less the same average number of flowers per plant, but the very late types have much smaller averages.

4. In clear weather flowers begin to bloom from about 11 a.m. to 2 p.m. Cloudy weather retards blooming. The second opening on the following day is earlier than the first. Flowers whose first opening is dealyed and very young buds which bloom partly the first time late in the afternoon, usually show a third opening. Flowers close soon after sunset.

5. Blooming in a branch or in a sub-branch is independent of other branches. Basal flowers are first to bloom, followed by others in a cymose arrangement.

6. No cleistogamous flowers occur under Niphad conditions.

7. Early strains set relatively more pods than late types, and are thus higher yielding.

8. A certain amount of sterility is due to empty pods which are usually located at the end of the branches. The number of such pods varies from season to season.

9. Under Niphad conditions most of the pods are one-seeded. The incidence of one- and two-seeded pods fluctuates greatly according to the season. Three-seeded pods are rare.

10. The two-seeded pods are located, as a rule, at the base of the branches. The seeds in such pods are irregular and one of them is invariably heavier than its companion.

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INHERITANCE OF GROWTH CURVE[1]

KOICHI EBIKO[2]

AMONG the genetic studies with regard to plant growth, the inheritance of common quantitative characters at a certain period of growth, such as height of plants, number of culms, or weight of plants, has already been worked out by many investigators, but very little is known about the growth curve which presents the entire course of development of plants from emergence to maturity.

The investigations described in this paper were undertaken with the purpose of determining whether the course of development of plants is inherited by analyzing the growth curves of parents and their progeny.

ROBERTSON'S GROWTH EQUATION

Approaching the growth problem from the chemical point of view, Robertson proposed a formula expressing the course of an autocatalytic, monomolecular reaction in his growth equation.

Already, a number of investigators (3, 4, 9)[3] have recognized that Robertson's growth equation is well fitted to the growth phase of various plants and animals; and also, in regard to the cereal crops, the possibility of making use of the equation has been accepted by Gaines and Nevens (4), Iwamoto (5), and Uyeda (10).

Attempts were made in the present investigation to make use of Robertson's growth equation. As given by Robertson (8) in its simple form, that is upon integration, this equation is expressed by the formula

$$\text{Log}\ \frac{x}{A-x} = K\ (t- t_1),$$

where x is the amount of growth which has been attained in time t, A is the maximum degree of growth attained in the growth cycle, K is a constant which is determined from a known value of x at a given time t, and t_1 is the time at which growth is half completed, that is when $x = \frac{1}{2}$ A.

In this equation, the developmental course of plants is indicated by the constant K, the magnitude of which determines the general slope of the growth curve.

Fig. 1, made after Gains and Nevens (4), shows three diagrammatic slopes of growth curves which are represented by three different values of K. From these curves it may be seen that the increase of slopes is accompanied by the increase of values of K.

[1]Contribution from the Department of Agronomy, Agricultural Experiment Station of the South Manchuria Railway Company, Koshurei, Manchuria. Also published in Japanese in the Scientific Papers dedicated to Dr. M. Akemine for the commemoration of the thirtieth anniversary of his professorship in the Hokkaido Imperial University, Japan, 1938. Received for publication March 12, 1938.

[2]Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 562.

MATERIALS AND METHODS

Spring wheat was used as the material in these studies. A cross was made between the early-ripening variety, Italian Spring, and the late-ripening variety, Sapporo Harukomugi No. 10, which appeared to the writer to possess some remarkably different habits of growth.

The growth curve of plants may be presented either on the basis of successive weights of the entire plant or on the basis of successive heights.

The author believes that the former method is more accurate for expressing the growth process in plants; but when such curves are to be constructed on the weight basis, different plants have to be used at each weighing and the data can

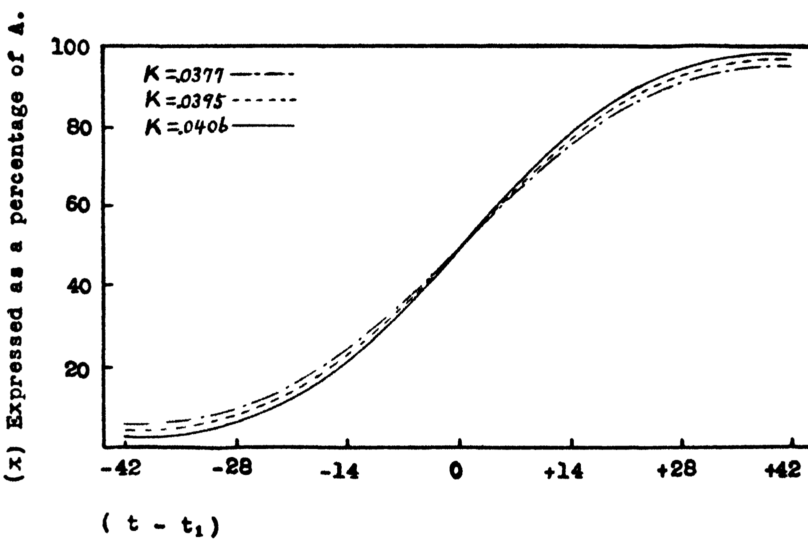

Fig. 1.—Showing form of the curve to Robertson's equation Log $\frac{x}{A-x}$ = K (t-t_1) for three values of K, *viz.*, 0.0377, 0.0395, and 0.0406. (After Gaines and Nevens.)

not be obtained from the same plants. On the contrary, the height data can be obtained from the same plants, and also the investigator is enabled to work with a larger number of plants than would be possible by any other method because of the small amount of time required to make the necessary measurements. For these reasons the height method was employed in this investigation.

The hybrid seeds were space-planted 10 cm apart in rows 60 cm apart without any fertilizers in an uniform field and at the same time seeds of parents were also sown in the same manner as controls.

The height of plants was measured at weekly intervals from 43 days after sowing in 1935 and from 41 days after sowing in 1936.

During the vegetative phases of growth measurements were made from the ground to the tallest leaves. After heading, when the top of the heads became higher than the tallest leaves, the measurements were made to the top of the heads.

At the calculation of constant K in Robertson's equation, by inserting the observed and calculated values of A, t_1, t, and x in the equation, a series of values of K was obtained corresponding to the different times t for the same plant.

The average of the several values thus obtained was taken as the value of K of the growth equation for each plant.

INHERITANCE OF CONSTANT K

As has been already stated, the magnitude of K determines the slope of the growth curve, hence it is necessary to examine the distribution of constant K in cross studies in order to ascertain whether the growth curve is inherited.

The results obtained on the F_1 plants and parents of the cross Italian Spring × Sapporo Harukomugi No. 10, grown in 1935, are are presented in Table 1.

From Table 1 it will be observed that the values of K of F_1 plants showed intermediate distribution between the ranges of K in both parents, and especially that the same average value, 0.0395, was obtained in reciprocal crosses.

This relationship is presented diagrammatically in Fig. 1, showing that the constant K may be controlled by Mendelian rule.

Data in Table 2 are the results obtained from F_2 and F_3 progeny grown in 1936.

Inspection of Table 2 shows that the frequency distributions of K of four F_3 families were considerably different and that, accordingly, their average values were not the same.

From these F_3 results it will be recognized that Mendelian segregation occurred in the F_3 population, and that, consequently, each family presented its own independent phenotype which must be controlled by some Mendelian factors. What factors are involved in the production of K is the next question.

As is shown in the frequency distribution of F_2 in Table 2, transgressive segregation for values of K occurred in the F_2 population. This indicates that there was transgressive inheritance with respect to the values of K, that is, that multiple factors were involved in the control of values of K.

From the above discussion, it can be emphasized that the constant K is inherited according to Mendelian rule, while, on the other hand, it is also necessary to keep in mind that K may at the same time be greatly affected by environmental conditions, from the fact that the differences between the values given in Table 1 (1935) and in Table 2 (1936) were noticeably great and also that a wide dispersion of frequency distribution of K was obtained in both 1935 and 1936.

SUMMARY AND CONCLUSIONS

There have not been reported, so far as is known to the writer, any studies on inheritance of the growth curve which expresses the entire course of development of plants, except by Ashby (1, 2). According to his investigations, the logarithmetic growth curve of F_1 which was obtained from corn plants during the vegetative period of growth, that is, from emergence to 70 days afterwards, was quite the same as the curve obtained from one of the parents, indicating that complete dominance occurred in this case.

TABLE 1.—*Frequency distribution for K values of the parents and F_1 progeny of the Italian Spring × Sapporo Harukomugi No. 10 wheat cross grown at Konuma, South Saghalien, in 1935.*

Parents and F_1 progeny	Number of plants for K value of																			Total	Average
	.030	.031	.032	.033	.034	.035	.036	.037	.038	.039	.040	.041	.042	.043	.044	.045	.046	.047	.048		
Sapporo Harukomugi No. 10	2	1	1	2	1	3	4	5	12	9	5	2	2	2	1					52	0.0377
Sapporo Harukomugi No. 10 × Italian Spring					1	1	5	2	5	5	4	9	5	2	2					41	0.0395
Italian Spring × Sapporo Harukomugi No. 10					1	1	2		4	2	8	6	3	1						28	0.0395
Italian Spring		1	1			1	1	3	5	5	3	6	8	4	2	2	2	1	1	46	0.0406

TABLE 2.—*Frequency distribution for K values of the parents and F_2 wheat cross, grown at Kinuma,*

Parents and progeny	Number of plants for K value of																	
	031	.032	.033	.034	.035	.036	.037	.038	.039	.040	.041	.042	.043	.044	.045	.046	.047	.048
Sapporo Harukomugi No. 10.	—	—	—	—	—	—	—	2	1	3	4	3	4	6	7	3	9	14
Italian Spring	—	—	—	—	—	—	—	—	—	—	—	1	—	5	3	4	5	6
F_2 progeny . .	1	1	1	6	4	7	7	6	27	31	39	45	62	67	76	82	57	65
F_3 progeny strain No. 12	—	—	—	—	1	—	1	1	—	3	2	4	4	6	4	5	8	5
F_3 No. 23 .	—	—	1	—	—	1	—	1	—	5	4	4	2	4	2	4	6	5
F_3 No. 65.	—	—	—	—	—	—	1	—	1	—	1	—	4	2	5	5	6	10
F_3 No 89.. .	—	—	—	—	—	—	—	—	—	—	1	—	2	—	1	1	1	2

In the present study, by using wheat plants, attempts were made to determine whether the growth curve produced by the employment of Robertson's growth equation is inherited. In Robertson's growth equation, the constant K is of special significance for the investigation of inheritance of growth curve because the slopes of growth curves are affected by variations in the magnitudes of the constant K.

Since it has been pointed out by Copeman (3), Klages (6), and Iwamoto (5) that the values of constant K are greatly affected by environmental factors, all plants of parents and progeny were cultivated under as nearly uniform conditions as it was possible to obtain. Under these circumstances, the values of K were calculated from the data obtained from weekly height measurements.

According to the results thus obtained, the values of K in F_1 hybrids were intermediate between those of the parents and the same average values were obtained in F_1 reciprocal crosses. Furthermore, in F_3 progeny, such results were obtained that the frequency distribution of K of each family was considerably different, showing that each family presented its own independent phenotype.

From these F_1 and F_3 results, the author arrived at the conclusion that the constant K may be inherited according to the Mendelian rule.

If this is so, the next question is, What factors are involved in the production of constant K? In reply to this question, the writer wishes to state that multiple factors may be involved in the control of values of K in view of the results of F_2 in which frequency distribution was transgressively segregated.

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and F_3 progeny of the Italian Spring×Sapporo Harukomugi No. 10 South Saghalien, in 1936.

Number of plants for K value of																				Total	Average
.049	.050	.051	.052	.053	.054	.055	.056	.057	.058	.059	.060	061	.062	.063	.064	.065	.066	.067	.068		
12	7	8	7	7	5	8	2	5	4	—	1	1	—	—	—	—	—	—	—	123	0.0492
7	7	9	7	12	9	6	5	3	3	—	2	2	1	—	—	—	1	1	—	99	0.0519
65	63	62	44	34	26	19	20	6	14	7	11	1	7	2	2	1	—	—	1	969	0.0473
11	6	11	7	9	7	9	2	3	4	2	—	—	3	2	—	1	—	—	—	121	0.0501
7	4	3	3	2	4	5	—	1	1	—	—	—	—	—	—	—	—	—	—	69	0 0473
7	10	7	8	8	2	7	1	3	3	1	1	1	2	1	1	—	—	—	—	98	0.0506
2	3	3	4	2	2	4	5	2	—	—	—	—	—	—	—	—	—	—	—	35	0.0514

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TIME OF CUTTING TIMOTHY: EFFECT ON THE PROPORTION OF LEAF BLADES, LEAF SHEATHS, STEMS, AND HEADS AND ON THEIR CRUDE PROTEIN, ETHER EXTRACT, AND CRUDE FIBER CONTENTS[1]

W. H. HOSTERMAN AND W. L. HALL[2]

THE proportion and chemical composition of the morphological parts found in the portion harvested for hay of the various leguminous hay plants when cut at different stages of maturity have been determined by a number of investigators. As a result of these studies the percentage of leaves has been used as an important factor in appraising the quality and feed value of legume hays. Similar detailed studies have never been made of the grasses used for hay. This paper presents some preliminary studies with reference to the proportion of leaf blades, leaf sheaths, stems, and heads of timothy harvested at different stages of maturity and their respective crude protein, ether extract, and crude fiber contents.

A review of the literature showed that a number of the agricultural experiment stations had collected data on the relation between time of cutting and yield of timothy *hay* per acre. Waters[3] reported, in addition to the yields, the composition of timothy hay cut at different stages of maturity. Trowbridge, *et al.*,[4] reported on the yields and composition of the heads, stalks with attached leaves, stubble, and bulbs for timothy cut at different stages of maturity. The stalks with attached leaf sheaths and leaf blades were not studied individually by these investigators, although they cited a need for such information.

PROCEDURE

During the summer of 1936 samples of ordinary timothy were collected at the Timothy Breeding Station, Bureau of Plant Industry, U. S. Dept. of Agriculture, Wooster, Ohio, for use in a percentage distribution and composition study of the various vegetative parts of the timothy plant that are utilized in the production of hay.

The several samples were cut during progressive stages of maturity and cured in the shade under such conditions that little, if any, of the plant parts were lost during drying. The five progressive stages of maturity were as follows: Nearly fully headed, early bloom, just past full bloom, about 10% of the heads straw colored, and heads mature. At Wooster during the season of 1936 these stages of

[1]Contribution from the Hay, Feed, and Seed Division, Bureau of Agricultural Economics, U. S. Dept. of Agriculture. Received for publication April 2, 1938.

[2]Marketing Specialist and formerly Associate Feed Technologist, now Chemist, Food and Drug Administration, respectively. The authors wish to acknowledge the assistance received from Morgan W. Evans, Division of Forage Crops and Diseases, Bureau of Plant Industry, who harvested the material used in this study.

[3]WATERS, H. J. Studies of the timothy plant, Part I. Mo. Agr. Exp. Sta. Res. Bul. 19.

[4]TROWBRIDGE, P. F., *et al.*, Studies of the timothy plant, Part II. Mo. Agr. Exp. Sta. Res. Bul. 20.

maturity were reached on the following dates: June 13, June 19, July 1, July 15, and July 28, respectively.

The dried samples were shipped to Washington for color measurements, separation into plant parts, and chemical analyses. Color measurements were made upon the unseparated cured plants from each cutting by the method developed and prescribed for use in measuring color under the official hay standards promulgated by the Bureau of Agricultural Economics, U. S. Dept. of Agriculture. The different timothy samples were then carefully separated by hand picking into leaf blades, leaf sheaths, stems, and heads, after which they were ground separately in a rotating knife type mill until all the material had passed through the 1-mm hole size screen.

Crude protein, ether extract, and crude fiber values were determined for each of the separations by the use of methods of analysis prescribed by the Association of Official Agricultural Chemists. From the percentage determinations of the various plant parts and the corresponding crude protein, ether extract, and crude fiber determinations for those parts the total percentage of crude protein, ether extract, and crude fiber in the hay obtained at each of the five stages of maturity was calculated. Corrections for variations in moisture were made by drying the material at 100° ± 3° C. in an electrically heated air oven for 18 hours.

RESULTS AND DISCUSSION

The separation analyses (Table 1) show that the weights of the leaf blades when compared with total plant weights decreased progressively from 38.2% for the early cut nearly full headed timothy to 10.0% for very late cut fully matured timothy. It is interesting to

TABLE 1.—*Total weight and color of timothy hay cut at different stages of maturity and the weight and percentage of total for leaf blades, leaf sheaths, stems, and heads.**

Date and stage harvested	Total weight, grams	Color		Leaf blades	
		Hue	% green†	Grams	%
June 13, nearly fully headed	500	10.45Y	100+	191	38.2
June 19, early bloom	528	10.00Y	100+	155	29.3
July 1, just past full bloom	658	9.13Y	100+	135	20.5
July 15, 10% heads straw colored	706	7.62Y	100+	81	11.5
July 23, heads mature	1,090	4.51Y	45	108	10.0

Date and stage harvested	Leaf sheaths		Stems		Heads	
	Grams	%	Grams	%	Grams	%
June 13, nearly fully headed	116	23.2	133	26.6	60	12.0
June 19, early bloom	105	19.9	174	33.0	94	17.8
July 1, just past full bloom	103	15.7	310	47.1	110	16.7
July 15, 10% heads straw colored	91	12.9	323	45.7	211	29.9
July 23, heads mature	122	11.2	422	38.7	437	40.1

*Calculated to an air-dry basis.

†For the purposes of interpreting hue readings in terms of percentage green color for timothy in the United States hay standards, a hue reading of 7.40Y is considered equivalent to 100% green color for field-cured hay. These samples were shade-cured and therefore have relatively high hue readings because shade-cured hay retains the green color to a greater extent than field-cured hay.

note that little decrease took place after the stage when 10% of the heads were straw colored. The relative weights of the leaf sheaths also decreased progressively although not as rapidly as the leaf blades. The relative weights of the stems increased from 26.6% for the nearly fully headed timothy to a maximum of 47.1% at full bloom and then decreased to 38.7% at the fully matured stage. The relative weights of heads increased from 12.0% to 40% with the greatest increase occurring after the plants had passed beyond the full bloom stage.

The calculated totals for crude protein, either extract, and crude fiber (Table 2) for the whole hay indicated a reduction in the crude protein content and an increase in the crude fiber content with very little change in the ether extract as the plant became more mature. However, when the plants were fully mature the large quantity of seed, which would naturally analyze high in crude protein and low in crude fiber, resulted in lowering the crude fiber content to the lowest of any stage of cutting and in increasing the crude protein content to approximately 8.0% which was almost as high as in the early stages of maturity.

The crude protein, ether extract, and crude fiber content of the various parts (Table 2) of the timothy plant indicated that the leaf blades were much higher in crude protein and ether extract and lower in crude fiber than the stems at all stages of maturity, while the leaf sheaths were intermediate between the leaf blades and stems. The crude protein content of the heads showed very little variation with increasing maturity except for the last sample, while the crude fiber content was about one-half as great when the heads were mature as it was in the early stages of maturity at which the timothy was cut.

The importance of this study as it relates to the production of high quality timothy hay is the interesting relationships which were shown between the crude protein, ether extract, and crude fiber in the various parts of the plant and the calculated totals for crude protein, ether extract, and crude fiber in the whole plant. Timothy cut prior to full bloom had 70% (Fig. 1) or more of the total protein of the hay in the leaf blades, leaf sheaths, and stems of the plant. Timothy hay which was allowed to stand until 10% of the heads were straw colored had at least 50% of the crude protein in the heads and that allowed to stand until fully mature had 70% of the crude protein in the heads. Since the higher crude protein content of the heads was due to the accompanying seeds, it is doubtful if timothy heads are of much value in field-cured hay because many of the heads might be shattered in the curing and storage operations and those seeds that are eaten are probably imperfectly digested.

The ether extract values indicated that the leaf blades contained over 50% of the ether extract when timothy was cut before the early bloom stage and that after the full bloom stage the ether extract in the heads increased rather rapidly.

The crude fiber values indicated that the stems contained 40% of the total crude fiber when the timothy was cut in the early bloom stage and 60% when allowed to stand until 10% of the heads of timothy were straw colored.

TABLE 2.—*Percentage of crude protein, ether extract, and crude fiber in timothy hay cut at different stages of maturity and the distribution of those constituents in the leaf blades, leaf sheaths, stems, and heads.**

Stage of maturity	Separation in relation to total weights, %	Chemical analysis			Relation to total		
		Protein, %	Ether extract, %	Fiber %	Protein, %	Ether extract, %	Fiber, %
		Whole Hay†					
Nearly fully headed	—	8.39	2.68	29.7	—	—	—
Early bloom	—	8.35	2.56	33.1	—	—	—
Just past full bloom	—	6.80	2.24	34.5	—	—	—
10% heads straw colored	—	6.99	2.53	33.5	—	—	—
Heads mature	—	7.94	2.67	28.7	—	—	—
		Leaf Blades					
Nearly fully headed	38.2	11.6	4.78	24.3	52.8	68.3	31.3
Early bloom	29.3	11.6	4.65	25.1	40.7	53.1	22.4
Just past full bloom	20.5	11.0	5.07	25.0	33.1	46.4	14.8
10% heads straw colored	11.5	9.04	5.35	25.0	14.9	24.5	8.7
Heads mature	10.0	6.60	5.35	25.9	8.31	20.2	8.0
		Leaf Sheaths					
Nearly fully headed	23.2	5.39	1.41	34.1	14.9	12.3	26.6
Early bloom	19.9	5.71	1.87	36.0	13.6	14.5	21.7
Just past full bloom	15.7	6.24	1.99	35.6	14.4	13.8	16.2
10% heads straw colored	12.9	7.42	2.68	35.8	13.7	13.8	13.7
Heads mature	11.2	6.08	3.05	35.3	8.56	12.7	13.9
		Stems					
Nearly fully headed	26.6	4.41	0.86	33.8	13.9	8.6	30.3
Early bloom	33.0	4.82	0.76	39.7	19.0	9.8	39.6
Just past full bloom	47.1	3.24	0.78	40.7	22.5	16.5	55.4
10% heads straw colored	45.7	2.94	1.07	43.0	19.2	19.4	58.5
Heads mature	38.7	2.76	1.28	41.6	13.5	18.7	55.7
		Heads					
Nearly fully headed	12.0	12.8	2.41	29.7	18.4	10.8	12.3
Early bloom	17.8	12.5	3.26	30.7	26.6	22.7	16.6
Just past full bloom	16.7	12.2	3.14	28.0	30.0	23.2	13.6
10% heads straw colored	29.9	12.2	3.59	21.5	52.2	42.3	19.1
Heads mature	40.1	13.8	3.22	15.6	69.6	48.3	21.9

*Calculated to an oven-dry basis. The average loss of weight on drying was 8.3%. None of the various parts analysed varied from this average by more than 0.5%

†The total percentages of protein, ether extract, and fiber given for the whole hay are calculated from the percentages for the constituent parts given in this table.

In the United States standards for alfalfa hay, leafiness has been used as a grading factor because data from various sources showed that the crude protein content of the leaves averaged about 2½ times the crude protein content of the stems. The leaves and stems of alfalfa cut at the earlier stages of maturity were higher in crude protein than the leaves and stems of alfalfa cut at the full bloom to seed stage,

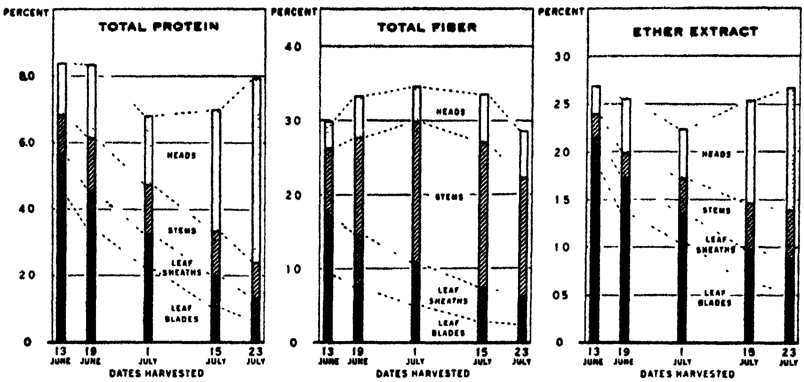

FIG. 1.—Relation of crude protein, crude fiber, and ether extract in the leaf blades, leaf sheaths, stems, and heads to the total crude protein, crude fiber, and ether extract in timothy hay at various dates of harvesting.

but there was no material change in the relation between the two. The early cut hay also had a higher percentage of leaves at time of cutting which materially influences the total protein found in the hay. Under these conditions the quantity of leaves present in the hay reflects the approximate protein content and, therefore, gives one a measure of feed value. As mentioned earlier in this paper, no data on the relation between leaf blades, leaf sheaths, stems, and heads of the grasses have heretofore been available. The results of this investigation indicate that the percentage of leaf blades and heads should be considered in determining the quality and feed value of timothy and perhaps other grass hays since the protein in the leaf blades decreased with maturity while the protein in the heads increased.

This type of study should be made with various strains of timothy selected for different percentages of leaf and stem, with those produced on different soil types, and under varying climatic conditions before definite conclusions can be drawn as to the full relationships of crude protein and crude fiber in the several morphological parts of the timothy plant. The results from the study described here will serve as a contribution to a knowledge of this subject. Similar studies should also be conducted with other grasses which are used for hay.

SUDAN GRASS MANAGEMENT FOR CONTROL OF CYANIDE POISONING[1]

F. T. Boyd, O. S. Aamodt, G. Bohstedt, and E. Truog[2]

UNDER certain conditions in Wisconsin, Sudan grass is one of the most satisfactory pasture grasses for midsummer. Its chief drawback, however, has been the possibility of poisoning of livestock by the cyanide or prussic acid which it may contain. The present investigation was undertaken for the purpose of determining the factors which give rise to a high poison content of Sudan grass in order that a program of management might be formulated which would eliminate or minimize the danger of poisoning.

OCCURRENCE AND FORMATION OF CYANIDE IN PLANTS

Since free or soluble cyanide is strongly toxic to plants, it seems reasonable to conclude that the accumulation of a considerable concentration of this poison in living plant tissue can only take place through the formation of an insoluble and non-toxic compound of the cyanide. In cyanogenetic plants, this compound may be one of several glucosides. In Sudan grass and sorghums, this glucoside is said to be *dhurrin*, which, on hydrolysis in the presence of the enzyme emulsion, yields glucose, parahydroxybenzaldehyde, and hydrocyanic acid. A very small portion of the cyanide may exist in living plant tissue in the free or non-glucosidic form.

No attempt is made in this paper to give more than a few of the many references pertaining to the subject in hand. The reader wishing further references is referred to a recent paper by Leeman (4)[3] which gives a rather complete discussion and an extensive bibliography relative to "Hydrocyanic Acid in Grasses." According to some of the theories reviewed and discussed by Leeman, cyanide is formed in certain plants due to a peculiar type of protein synthesis in which the nitrogen absorbed as nitrates from the soil by cyanogenetic plants, is changed to the form of hydrocyanic acid as an intermediate stage between nitrates and amino acids in the formation of proteins.

As rapidly as hydrocyanic acid is formed, it combines with glucose and benzaldehyde to form a non-toxic glucoside, which, in turn, does not accumulate if conditions are favorable for the rapid and complete synthesis of proteins. Since nitrogen is an essential constituent of HCN, it is probable that toxic quantities of cyanophoric compounds would not accumulate in nitrogen-starved plants. If the plant is not furnished with an adequate supply of available phosphorus, the for-

[1]Joint contribution from the Departments of Soils, Agronomy, and Animal Husbandry, University of Wisconsin, Madison, Wis. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station.

[2]Assistant in Soils and Agronomy, and Professors of Agronomy, Animal Husbandry, and Soils, respectively. The writers are indebted to Doctors F. B. Hadley and E. R. Carlson of the Department of Veterinary Science for assistance in connection with toxicological matters and Professor K. P. Link for advice in connection with the development of a method for the determination of cyanide in plants.

[3]Figures in parenthesis refer to "Literature Cited", p. 582.

mation of certain proteins is inhibited and the accumulation of cyanophoric compounds may be accentuated.

EFFECT OF CYANIDE ON ANIMALS

The various species of animals react differently when fed plants containing cyanophoric glucosides. These differences are caused by different anatomical structures and different detoxifying abilities of various animals. Cattle and sheep are ruminants and both are known to be subject to poisoning by cyanophoric glucosides. The paunch or rumen of these animals is neither strongly acid nor alkaline in reaction, contains a large flora of micro-organisms, and considerable quantities of the enzyme emulsion. An excellent medium is thus provided for the hydrolysis of the glucoside with the liberation of the toxic agent—hydrocyanic acid. Horses and hogs, being non-ruminants, have only one stomach which is strongly acid in reaction due to the presence of HCl. This HCl reacts with the liberated HCN to form much less toxic substances as follows: $HCN + HCl + 2H_2O$

$$\longrightarrow \underset{\text{Formic acid.}}{HC\begin{matrix}=O\\ \diagdown OH\end{matrix}} + NH_4Cl$$

The toxifying action of HCN is almost immediate, that is, as soon as it is liberated from the glucosides. In a discussion of the toxicology of hydrocyanic acid, Hadley and Kozelka (3) state that the specific action of HCN on animals is that it inhibits the oxygen-activating enzyme, indophenol oxidase. When this happens, the release of energy through oxidation decreases, and if this goes far enough sickness and death result. The symptoms of this sickness are increase in rate and depth of respiration, increased pulse rate, no response to stimuli, and spasmodic muscular movements. Experimentally, it has been shown by various investigators that it takes a dose of about 1 gram of HCN to kill a cow of 1,000 pounds in weight. The amount may vary some depending on the detoxifying capacity and physical resistance of the animal.

Calculating on the basis of work done by Loevenhart, *et al.*, and by Turner and Hulpien, quoted by Hadley and Kozelka (3), it is found that dogs and rabbits can detoxify at the rate of approximately 0.5 mgm HCN per hour per pound of body weight without any toxic effects. Thus, on this basis, a 1,000-pound cow should be able to detoxify at the rate of about 0.5 gram of HCN per hour. It is therefore possible for cattle to consume forage containing small amounts of cyanide without ill effects or symptoms of cyanide poisoning. It is only when the poison enters the blood stream at a greater rate than the detoxifying rate of the animal that fatal poisoning follows.

EFFECT OF VARIOUS FACTORS ON CYANIDE CONTENT OF SUDAN GRASS

The factors influencing the amount of cyanide in plants have not been definitely determined and many conflicting theories regarding the matter have appeared in literature.

Manges (5) of Kansas in 1935 stated as follows: "Hydrocyanic acid is not found in appreciable quantities in healthy growing plants. The acid develops only when the normal growth of the plant has been retarded or stopped by drought, frost, bruising, trampling, wilting, mowing, and other causes. . . . . . The mature plant contains a smaller percentage of potential acid than the young plant, and plants grown on fertilized soil, especially soils which have been fertilized with nitrates, contain less than those grown on poor soil. . . . . . Immediately after the first frost in autumn there may develop a heavier concentration of acid than is normally present in the plants."

Rogers and Boyd (8) of Minnesota state that the pasturing by sheep and cattle of frozen Sudan grass containing relatively large amounts of hydrocyanic acid (according to picrate test tube test) did not result in sickness. They believed hydrocyanic acid to be most abundant in rapidly growing plant tissues, and claimed that Sudan grass which was badly stunted by drought contained less cyanide than plants growing under more favorable conditions.

Maxwell (6) in 1903 found HCN to be highest in sorghum in the early stages of growth, and that the amount of poison thus formed is governed largely by the nature of the soil, being higher when the soil is rich in the nitrogenous constituents of plant food.

Willaman and West (11) concluded that climate and variety of sorghum may be more important factors than supply of available soil nitrogen in determining the content of cyanide in sorghum tissue. Later, Willaman (12) stated that plants which are in an unhealthy condition due to malnutrition, insect injury, improper transpiration, or inadequate moisture supply are usually higher in content of cyanide than healthy ones.

Swanson (10) found the most hydrocyanic acid in Sudan grass when the plants were young and in a vigorous condition. He also (9) reported that freezing of Sudan grass did not cause a decrease in the cyanide content found if the test is made before the plants thaw and wilt. After thawing and wilting the cyanide content dropped rapidly.

Moody and Ramsey (7) concluded that sorghum-Sudan grass hybrids are especially high in poison and dangerous to pasture.

Acharya (1) has suggested the ensiling of sorghum as a means of destroying the poison principle. His results with sorghum support those of the present investigation as regards the influence of stage of growth, time of day, and drying on the cyanide content.

DETERMINATION OF CYANIDE IN PLANT TISSUE

In order to make possible a thorough study of the factors involved in the poisoning of livestock by Sudan grass, it was found desirable to investigate the methods which have been proposed for the determination of cyanide in plant tissue. As a result of this investigation by Boyd and Truog, a very satisfactory method for this purpose has been evolved.[4]

In this method, 8 grams of chopped plant tissue are placed in a Kjeldahl flask along with 300 cc of water and 5 cc of chloroform. The contents of the flask are then subjected to steam distillation causing the liberated HCN to distill. After passing through a condenser, the HCN is caught in an alkaline solution. Five cc of this distillate are then treated in a test tube or other suitable vessel with 5

[4]It is proposed to publish the details of the method elsewhere.

cc of an alkaline picrate solution, causing, on heating in a water bath, the development of a red color whose intensity is proportional to the amount of cyanide present. This color is then compared with proper standards, and thus the amount of cyanide involved is determined. The method is relatively simple and expeditious, and is believed to be considerably more reliable than some of the other methods which have been proposed. Its use proved invaluable in the studies that followed.

SOIL FERTILITY AS A FACTOR INFLUENCING THE AMOUNT OF CYANIDE IN SUDAN GRASS

On a single occasion in July, 1936, 17 cows in a herd of 35 died while pasturing on short, stunted Sudan grass near Argyle, Wisconsin. Samples of the short stunted Sudan grass were collected from this field and analyzed and found to contain 346 mgm HCN per 100 grams of dry tissue. Sorghum-Sudan hybrids were not found in this field. The soil was acid and deficient in available phosphorus but contained 50 pounds of nitrate nitrogen per acre. Under greenhouse culture, Sudan grass grown on the same soil when young contained twice as much cyanide as plants in a similar stage grown on soil of medium fertility, and eight times as much cyanide as plants, also in a similar stage, grown on a soil of high and well-balanced fertility. These findings suggested further studies of the effect of fertilizer treatments on the cyanide content of Sudan grass and sorghum.

INFLUENCE OF NITROGEN FERTILIZATION ON CYANIDE CONTENT

The addition of nitrogen fertilizers to soils deficient in nitrogen increased the cyanide content of Sudan grass and sorghum grown on these soils. Similar treatment of soils well supplied with nitrogen had little effect on the cyanide content of the plants produced. It was found that stunted plants, when chlorotic due to a nitrogen deficiency, contained very little cyanide.

The effect of heavy applications of nitrogen fertilizers in pot tests on the cyanide content of Sudan grass at different stages of growth is given graphically in Fig. 1. These results indicate conclusively that Sudan grass in both the fertilized and unfertilized pots was highest in cyanide content at the earliest stages of growth. The Sudan grass which received nitrogen fertilizer was consistently higher in cyanide than the unfertilized grass, but was below the toxic limit after it had reached a height of 1 foot.

Some sorghum plants, grown in pots, became quite chlorotic due to lack of nitrogen when about 8 inches in height. These plants had a low cyanide content. A different nitrogen fertilizer was added to each of three of these pots. A fourth was left unfertilized. The fertilized plants changed rapidly from yellow to dark green in color and increased in cyanide content. Alway and Trumbull (2) have reported similar findings. The results, presented in Fig. 2, reveal marked increases of cyanide content due to the addition of the three nitrogen fertilizers, urea, potassium nitrate, and ammonium sulfate. The slight differences obtained with the three fertilizers in increase of cyanide content are probably due more to various experimental errors, such

as those involved in sampling, than in actual differences in the effect of the three nitrogen fertilizers.

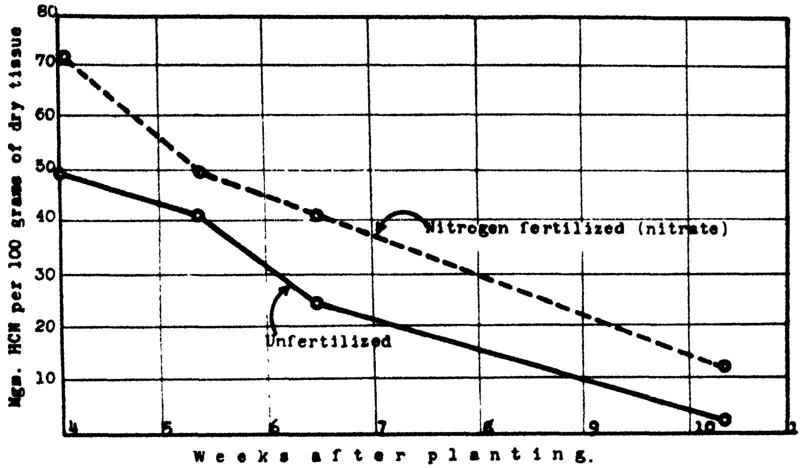

FIG. 1.—Cyanide content of nitrogen-fertilized and unfertilized Sudan grass at different stages of growth (pot test).

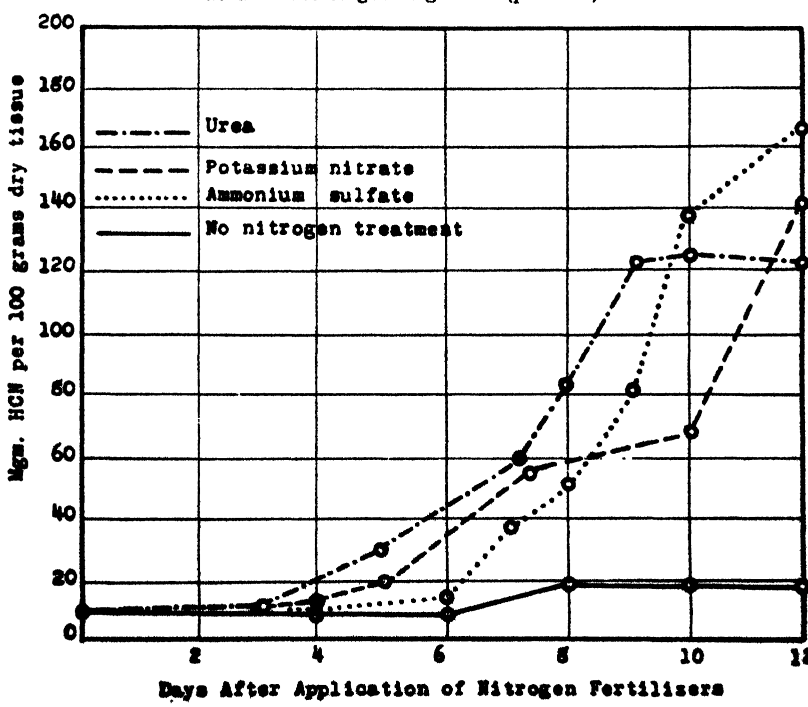

FIG. 2.—The cyanide content of sorghum after fertilization with various nitrogen fertilizers. Plants were grown in pots and fertilized when 8 inches high.

INFLUENCE OF PHOSPHATE FERTILIZATION ON CYANIDE CONTENT

When adequate amounts of phosphate fertilizer were applied to phosphorus-deficient soils, Sudan grass planted thereon grew rapidly, and six weeks after planting only small amounts of cyanide were found in the Sudan grass. On the other hand, high concentrations of cyanide were found in plants of the same age grown on soils deficient in phosphorus. Since phosphorus is an important constituent of the nucleo-proteins, which are an essential constituent of all cells, an adequate supply of phosphorus is needed if rapid cell division and plant growth are to take place. An adequate supply of avialable phosphorus thus tends to decrease the cyanide content in two ways: First, it makes possible and speeds up the formation of certain proteins which use up nitrogen that might otherwise accumulate in the form of cyanide. Second, by speeding up cell division, plants more rapidly reach the stage of lower cyanide content. Sudan grass grown in greenhouse beds on a soil very deficient in available phosphorus but well supplied with other plant nutrients, contained 127.0 mgm HCN per 100 grams of dry matter 30 days after the date of planting. Sudan grass grown in similar beds which received complete fertilizer treatment was found to contain only 36.3 mgm HCN at the same date. Sorghum plants grown in sand cultures without phosphate fertilization contained 427.2 mgm HCN per 100 grams of dry tissue six weeks after planting, while sorghum plants similarly grown with complete fertilizer treatment contained only 25.3 mgm at the same age.

INFLUENCE OF POTASH FERTILIZATION ON CYANIDE CONTENT

The addition of potash fertilizers to pots containing soil in which Sudan grass and sorghum were grown, produced little, if any, effect on the cyanide content of either Sudan grass or sorghum. These greenhouse results were verified with field experiments. None of the soils in which these plants were grown was especially low in available potash. For that reason a stunted growth due to potash deficiency did not develop in the untreated areas and the influence of a really low level of available potash was not determined.

STAGE OF GROWTH AS A FACTOR INFLUENCING THE CYANIDE CONTENT OF SUDAN GRASS

The results of greenhouse tests conducted during March and April, 1937 and presented in Fig. 1, show that the cyanide content of Sudan grass is highest in the earlier stages of growth. Later in the season, samples of Sudan grass from fields were collected to check this matter. On August 3 on the Fred Techam farm, Middleton, Wis., 10 cows broke into a quarter-acre paddock of second growth Sudan grass which had reached a height of about 4 inches and was dark green in color. Eight cows died within a half-hour after entering the paddock. Samples of grass and soil were taken from this paddock to the laboratory for analysis. The soil was found to be well supplied with available

phosphorus (100 to 125 pounds per acre) and available potash (250 to 325 pounds per acre), and contained 25 to 35 pounds of nitrate nitrogen per acre. This green, second growth Sudan grass contained 126.5 mgm HCN per 100 grams dry matter. In this case, the early stage of growth was the factor responsible for the high content of cyanide.

The results given in Fig. 3 were obtained from second growth Sudan grass grown on the farm of A. J. Glover, Fort Atkinson, Wis. These results were obtained in connection with an interesting experi-

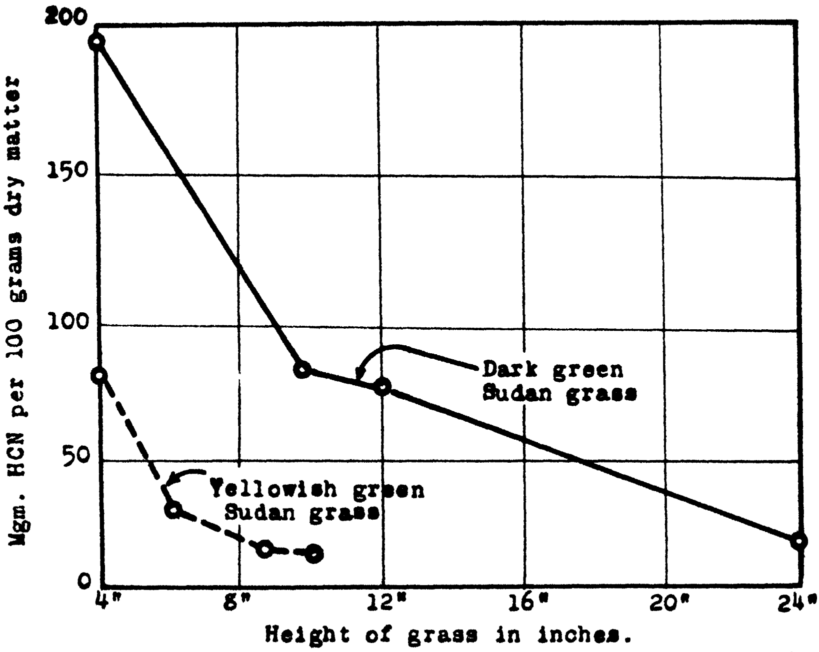

FIG. 3.—Relation between height and cyanide content of dark green and yellowish green second growth Sudan grass on A. G. Glover farm. Samples were taken at weekly intervals.

ment. Mr. Glover harvested a hay crop consisting of a mixture of Sudan grass and soybeans grown on a relatively fertile lowland field. The second growth of Sudan grass was dark green in color. When about 5 inches in height several samples were collected and tested for cyanide content. All of the samples had a high cyanide content. A heifer was allowed to graze some of this Sudan grass which was about five inches in height. After eating for about 10 minutes, the heifer began to stagger and refused to eat any more of the Sudan grass. A veterinarian was present and stated that the heifer showed symptoms of cyanide poisoning. Two days later, six cows were turned into this field of short Sudan grass. Three of the cows were thin and in poor physical condition, while the other three were in good condition. Two of the emaciated cows, after eating for 15 minutes, laid down and showed marked symptoms of acute cyanide poisoning. It was neces-

sary to administer an intravenous injection of sodium thiosulfate to revive these two cows and prevent death. Later, after this Sudan grass had reached a height of about 18 inches, tests showed that the cyanide content had gone down to a low level. Mr. Glover then pastured the grass without any ill effects to his cattle.

INFLUENCE OF VARIETY AND SPECIES OF SUDAN GRASS ON CYANIDE CONTENT

Sorghums are often much higher in cyanide content than Sudan grass. Eight strains of Sudan grass were grown in the greenhouse and analyses of the plant tissue produced showed differences between strains in cyanide content. Only one out of seven selected inbred strains was found to contain appreciably less cyanide than the commercial strain used in these experiments. All strains examined were found to be high in cyanide at the very young stage in both first and second growths, but the height at which the plant reached the non-toxic condition varied considerably. Some of the data are presented in Table 1.

TABLE 1.—*A comparison of the cyanide content of several strains of Sudan grass at approximately 12 inches in height.*

Strain	Mgm HCN per 100 grams dry tissue
T_{13}	12.00
T_{14}	28.40
O_{22}	37.72
O_1	49.72
T_{10}	88.04
T_{12}	32.52
Nebraska strain	65.88
Commercial strain	30.00

From these data it appears that the strain T_{13} is the only strain whose cyanide content was significantly lower than the commercial strain. When T_{13} was tested at a much earlier stage of growth, it was found to be relatively high in cyanide content but lower than some of the others. Two weeks after the above tests were made, both the commercial strain and T_{13} were equally low in cyanide.

EFFECT OF ENSILING ON CYANIDE CONTENT OF SUDAN GRASS

An experiment was conducted to determine the effect of ensiling on the cyanide content of Sudan grass. It was believed that the fermentation processes which take place when grass is ensiled would decompose the toxic cyanide and form non-toxic organic acids.

Three milk bottles were tightly packed with Sudan grass high in cyanide content and closed with a stopper having a valve attachment which would allow the escape of gases but prevent any gases entering from the atmosphere. In bottle No. 1, the grass was treated with molasses; in bottle No. 2, with a mixture of HCl and H_2SO_4 similar to the well-known A.I.V. method; while in bottle No. 3 was given no additional treatment. The Sudan grass placed in the bottles came from the same lot of grass which was high in cyanide content (94.5 mgm

per 100 grams dry tissue). After six weeks of fermentation, the bottles were opened and the grass tested. It was found that no significant loss of cyanide took place in either the molasses-treated grass or the untreated grass. A slight decrease in cyanide content was observed, however, in the acid-treated Sudan grass of bottle No. 2. As a result of this experiment it is concluded that if Sudan grass is poisonous at the time of ensiling, it will, at least under some conditions, remain toxic after ensiling for several weeks. It is to be noted that Acharya (1) reports a greatly reduced cyanide content of sorghum after ensiling for two months.

EFFECT OF FROST ON CYANIDE CONTENT OF SUDAN GRASS

Contrary to the opinions of some (5), no increase in the cyanide content was found when Sudan grass was frosted. Several farmers' samples of frosted plants were received and analyzed. None of these samples was found to be high in poison, though none of the grass represented by these samples was short and poisonous at the time of freezing. The Sudan grass in some field experimental plants was dark green in color and about 2 feet in height at the time of the first frost. Samples of this grass were collected and tested for cyanide before and after the first frost. The cyanide content was low in both cases and no higher after the frost than before the frost. Cattle were allowed to graze some of this Sudan grass after a killing frost, but symptoms of cyanide poisoning did not develop. These observations indicate that freezing does not materially increase the cyanide content of Sudan grass. If favorable weather for growth follows a killing frost, the Sudan grass will send forth new shoots and leaves which are apt to be very high in cyanide, and if pastured, cause cyanide poisoning. When this happens, it is of course natural to infer that it is the frosted grass that caused the poisoning rather than the new growth.

INFLUENCE OF DROUGHT ON CYANIDE CONTENT OF SUDAN GRASS

The belief that drought is one of the chief factors involved when Sudan grass becomes poisonous has been supported by some investigators (4, 11). The writers subjected some Sudan grass about a foot in height and low in cyanide content growing in the greenhouse and also in the field, to drought. In neither case did an increase in cyanide content take place. However, when, due to drought, water is withheld from short, dark green Sudan grass, a high cyanide content may persist, because the grass is unable to grow out of the high cyanide stage. Thus drought probably operates as a factor largely by keeping the plants small, in which stage they are generally higher in cyanide content than when larger. Drought keeps the plants small by withholding water and probably by lessening much more the availability of phosphates to plants than that of nitrogen.

EFFECT OF DRYING ON CYANIDE CONTENT OF SUDAN GRASS

It has been held by some (5, 9) that cyanogenetic plants lose their toxic properties by drying or being made into hay. The results obtained by analyzing plants grown in the greenhouse and dried in various ways are presented in Table 2. These results show that air drying did not lower the cyanide content. Plants that were high in poison at the time of cutting did not lose appreciable quantities of cyanide due to air drying or sun curing. When the plants were oven-dried at a temperature of 115° C, however, there resulted a very significant decrease in the content of cyanide. Several samples of Sudan grass hay which were tested for farmers contained only traces of the poison. None of these samples represented grass less than 1 foot in height at the time of cutting. Thus, if the grass is low in cyanide content at the time of cutting, hay made from this grass will also be low in content of cyanide; however, if small green plants with a high cyanide content are made into hay, the hay will probably, if carefully cured and stored, have a high cyanide content.

TABLE 2.—*Effect of sun curing and air and oven drying on the cyanide content of sorghum and Sudan grass.*

Sample	Cyanide content in mgm HCN per 100 grams dry tissue			
	Fresh tissue	Air dried	Oven dried	Sun cured
		Sorghum		
Entire plant	193.6	204.0	27.6	—
Leaves only	372 4	370.7	97.0	350 5
		Sudan grass		
1	59.5	61.3	—	53.1
2	47.6	47.6	—	—
3	60.4	58.4	—	—

DIURNAL VARIATION IN CYANIDE CONTENT

Greenhouse experiments were conducted to determine the diurnal variation in the cyanide content of Sudan grass and sorghum. Samples were taken for analysis at 8:00 a.m., 1:00 p.m., and 7:00 p.m. The results obtained for Sudan grass harvested at 1:00 p.m. were about 30% higher than those obtained for grass harvested in the morning or evening. In the case of sorghum, the cyanide content at 1:00 p.m. was also considerably higher than in the morning and evening. It is to be noted that these results accord with those reported by Acharya (1). In grazing practice, these differences are probably of little significance except in borderline cases.

The data obtained from this experiment were subjected to statistical analysis. The differences between the cyanide content at noon, morning, and evening were found to be significant. The percentage error found ranged between 7 and 9%, depending on the mean of the cyanide contents of the plants tested. Some of the data are given graphically in Fig. 4.

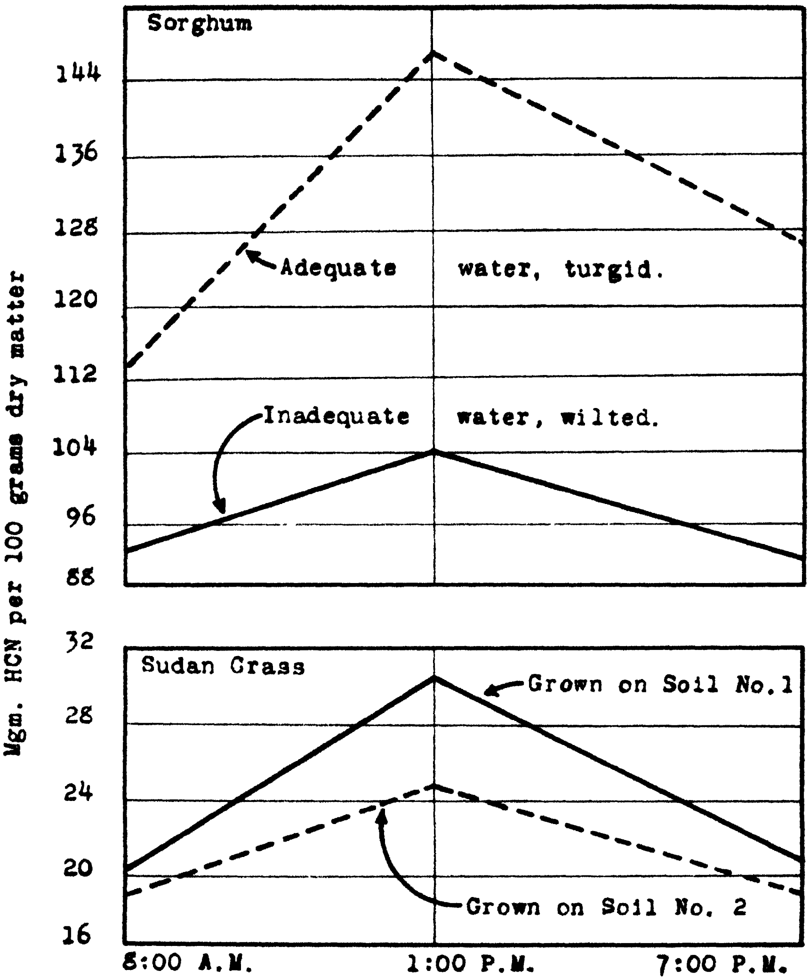

FIG. 4.—Diurnal variation in cyanide content of sorghum and Sudan grass grown in the greenhouse at approximately 1 foot in height.

THE SAFE LIMIT OF CYANIDE CONTENT

During 1937, nearly 500 samples of Sudan grass from farmers' fields were tested for their cyanide content. Reports of these tests were made as to their relative degree of toxicity in accordance with the following schedule:

Mgm HCN per 100 grams dry tissue	Relative degree of toxicity
0–25	Very low (safe to pasture)
25–50	Low (safe to pasture)
50–75	Medium (doubtful)
75–100	High (dangerous to pasture)
>100	Very high (very dangerous to pasture)

Of the 500 samples analyzed, 20 were reported to represent dangerous or very dangerous Sudan grass. Six samples were reported as being doubtful. All the rest of the samples contained less than 50 mgm HCN per 100 grams of dry tissue and were reported to represent grass that was safe to pasture. No cases of poisoning occurred in pasturing according to these recommendations. When fields of Sudan grass were found to be unsafe to pasture, recommendations were made to delay grazing until the grass reached a height of at least 18 inches. The farmers followed this precaution and in no case did they encounter any fatal poisoning. The only fatal case of poisoning of cattle from pasturing Sudan grass in Wisconsin in 1937 that came to the attention of the writers was the Fred Techam case previously mentioned. In this instance, hungry cattle broke into a small paddock of short, green, second growth Sudan grass.

ELIMINATION OF CYANIDE POISONING BY PROPER MANAGEMENT

In view of the results obtained, the following program of Sudan grass management is recommended which not only minimizes the danger of cyanide poisoning but also provides the most pasturage from a given area.

For continuous grazing of Sudan grass during the summer months, it is desirable to have two or more fields of Sudan grass so that the cattle may be rotated from field to field, thus obviating the necessity of pasturing a field when much of the grass consists of small new growth, as is finally the case when a relatively large field is slowly grazed down. Rotational grazing of Sudan grass has other notable advantages. It makes possible the production of more pasturage from a given area because the grass is allowed to get a good start and produce a large amount of leaf surface before being pastured. It is in the actively growing young leaves that much of the carbohydrate and protein manufacture takes place, and if these leaves are grazed off as soon as formed, the grass is prevented, at all times, from having the advantage of a period when rapid manufacture of carbohydrates and proteins and hence rapid growth can take place. In rotational grazing, the grass has the advantage of rapid growth that comes only after a good start is once made. Still another advantage of rotational grazing is that it causes a more uniform removal of all of the old growth and then provides for a rest period during which time the pasture becomes cleansed and thus the pasturage made more palatable again.

To insure a good growth of Sudan grass, soil moisture should be conserved and stored by plowing the land in the fall or early spring so as to aid the entrance of water and then cultivating occasionally in early spring to prevent weed growth and excessive loss of moisture during the interval before the land is sown to Sudan grass. Under Wisconsin conditions, for continuous summer grazing, the first field should be sown during the latter part of May and the second and any others not later than June 15. On well-prepared and fertile land the first field should be ready to graze during the early part of July.

To obtain the most forage, low in cyanide, Sudan grass should not be grazed until it has reached a height of at least 18 inches. When the Sudan grass area is divided into two or more fields, grazing of a smaller area at a time is made possible. This forces the cattle to remove quite completely and uniformly, in a relatively short period, the growth which has accumulated. The proportionately small amount of new growth which is produced during this period is mixed with so much older growth that there is no danger of poisoning. As soon as the first field is grazed down, the cattle are rotated to the second field, where the grass should then be at least 18 inches in height. This gives the grass in the first field full opportunity to produce new shoots and leaves, making possible rapid photosynthesis and growth. When the grass in this first field has again reached a height of 18 inches or more, the field is again ready for grazing. The other field or fields are managed similarly. If other pasture than Sudan grass is available, the cattle may, of course, be rotated from the Sudan grass to that pasture and back again.

To insure hay of low cyanide content, Sudan grass should not be cut until it has reached a height of at least 2 feet. On fertile soils, good palatable hay, high in protein, can be obtained even if the grass is allowed to grow several feet in height.

SUMMARY

The purpose of this investigation was to determine the factors involved in cyanide poisoning of livestock by Sudan grass in order that a program of crop management might be formulated which would eliminate this danger. In the course of this investigation, a rapid chemical method for determining the cyanide content of Sudan grass and sorghum was developed. This method has proved invaluable in elucidating the factors involved and in determining whether or not Sudan grass is safe to pasture. The results obtained are summarized as follows:

1. It is the *short, dark* green Sudan grass which is high in cyanide and which is dangerous to pasture. Second growth, after pasturing or removal of a hay crop, when short and dark green is especially dangerous. Sudan grass which is 2 feet or more in height, whether first or second growth, is low in cyanide and is relatively safe to pasture. Sudan grass, short or tall, which is of a pale or yellowish green color is low in cyanide and is relatively safe to pasture.

2. Both from the standpoint of danger from poisoning and possibility of obtaining the most pasture, Sudan grass should usually not be pastured until it has reached a height of 18 inches and better, 2 or 3 feet. This is best accomplished by having two or more fields so that the cattle may be rotated from one field to another.

3. A high level of available nitrogen and a low level of available phosphorus in the soil tend to increase the poison content, while a low level of available nitrogen and a high level of available phosphorus have the opposite effect. A high cyanide content may still occur in short plants, however, especially in the second growth, even though the level of available phosphorus is high. A high level of available

phosphorus along with other favorable growth factors makes it possible for the plant to attain quickly a height of 2 to 3 feet, at which stage it is relatively free of poison.

4. Drought probably operates as a factor, largely by keeping the plants small when they are always much higher in cyanide than when larger. Drought keeps the plants small by withholding water and probably lessening the availability of phosphates to plants much more than that of nitrogen. Fall or early spring plowing followed by cultivation should be practiced on fields to be sown to Sudan grass so as to conserve moisture and prevent the ill effects of drought.

5. When Sudan grass is dried and made into hay without undue exposure and then well stored, the cyanide content does not change greatly. Since it is usually not cut for hay until it reaches a height of 3 feet or more, there is little if any danger of cyanide poisoning from Sudan grass hay. However, if short Sudan grass, high in cyanide, is made into hay, it will be dangerous as a feed.

6. Cattle when turned into Sudan grass of high poison content usually stop eating after about 15 minutes due to the action of the poison. If the animals are not too hungry and are in a high state of vigor, they may stop eating before they take a fatal dose. Cattle vary in the amount of cyanide that it takes to be fatal. If they are in a low state of vigor and very hungry, they are more apt to eat a fatal dose than when the opposite is the case.

7. When there is doubt as to possible danger, samples should be collected and tested for poison. The whole field should be examined carefully. If spots of small Sudan grass are found, samples from each of these should be taken for analysis.

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CAPILLARY CONDUCTIVITY OF PEAT SOILS AT DIFFERENT CAPILLARY TENSIONS[1]

B. D. WILSON AND STERLING J. RICHARDS[2]

CAPILLARY conductivity is a convenient term for expressing the ability of an unsaturated soil to conduct water. The term is defined as the amount of water which in unit time crosses a unit area perpendicular to the direction of flow when the water-moving force is unity. The capillary conductivity of a soil depends not only on the type of soil but also on the moisture content.

In a previous report from this laboratory, Richards and Wilson[3] presented measurements of capillary conductivity for two peat soils. One of the soils was taken from the surface zone of a virgin deposit of woody peat. The other soil was collected from a cultivated area of the same deposit. The area had been tilled annually for a period of about 50 years. In the present report capillary conductivity values are recorded for four other peat soils under varying conditions of moisture. The moisture conditions of the soils are expressed in terms of capillary tension. Embodied in the report is a comparison of the values obtained for the peat soils used in this investigation with the values reported by Richards[4] for three mineral soils of different textures.

METHOD OF PROCEDURE

The method employed in measuring the capillary conductivity of the soils is described in the article by Richards and Wilson, referred to above, hence only a brief description of the method will be given here. The soil to be studied was placed in telescoping brass cylinders between two hollow porous cells. The flow of water to and from the soil took place through the walls of the cells at pressures less than atmospheric pressure. Such pressures are commonly referred to as capillary tensions. Enough soil was placed in the cylinders to form a column of soil about 12 cm in length and 12.1 cm in diameter. In no case during the tests did the soil expand or contract sufficiently to change the length of the column 0.1 cm. The force causing water to move through the soil was supplied by controlling the capillary tensions at the two ends of the soil column at different values. The column of soil was placed horizontally making a consideration of gravitational forces unnecessary. Evaporation of water from the soil was prevented by placing the cylinder containing the soil in an air chamber saturated with water vapor. Burette tubes were employed for reading the flow of water to and from the soil. During the experiments room temperature was controlled automatically at 24.8° ± 0.1° C. Two complete units of the apparatus were available for the work, making it possible to procure individual records for two soils simultaneously.

[1]Contribution from the Departments of Agronomy and Physics, Cornell University, Ithaca, New York. Received for publication April 6, 1938.

[2]Professor of Soil Technology, Cornell University; and formerly Graduate Assistant in Physics, Cornell University, now Assistant Soil Physicist, New Jersey Agricultural Experiment Station, respectively.

[3]RICHARDS, L. A., and WILSON, B. D. Capillary conductivity measurements in peat soils. Jour. Amer. Soc. Agron., 28: 427–431, 1936.

[4]RICHARDS, L. A. Capillary conductivity data for three soils. Jour. Amer. Soc. Agron., 28: 297–300, 1936.

Capillary conductivity, (K) was calculated from the expression $K = Q/t \times Ld/A\Delta T$, where Q/t is the cc of water per second passing through the soil column, L is the length of the soil column in cm, A is the area of the soil column in square cm, d is the density of water in grams per cc, and ΔT is the difference in capillary tension at the two ends of the column expressed in dynes per square cm.

SOILS USED IN THE INVESTIGATION

Two virgin and two cultivated peat soils were used in the investigation. One of the virgin soils was taken from the surface foot of a peat despoit composed of dark brown, granular woody peat containing an admixture of reed and sedge peat. The deposit is about 4 feet in depth underlain with Chara and shell marl. This soil is designated as peat A (virgin). Another sample of soil taken from the surface foot of a contiguous area which had been cultivated annually for about 20 years is designated as peat A (cultivated, 20 years). This soil having been reduced to a fine state of division during the extended period of cultivation was more uniform in character than was peat A (virgin).

A third sample of soil, made up largely of grayish brown, well-decomposed woody peat, and designated as peat B (virgin, screened), was collected from the upper foot of an uncleared despoit. The sample was screened to remove the larger fragments of wood and the roots of recent vegetation. Screening made the soil more or less uniform in character. The deposit from which the sample was taken is about 3 feet in depth resting on non-calcareous gray sand. A fourth sample of soil, designated as peat C (cultivated, 2 years), was collected from a deposit which had been cleared two years previous to the time of collection and which had been tilled during two cropping seasons. The soil was composed of grayish brown woody peat and it was lumpy from coarse woody debris. The deposit was approximately 30 feet in depth underlain with calcareous, grayish blue clay.

Air-tight containers were used for storing the soils until they were placed in the telescoping cylinders of the apparatus. At that time the soils had lost little moisture, and with the exception of peat B (virgin, screened), they possessed much of the original field structure. In filling the cylinders the soil was subjected to some tamping in order that large voids would not exist in the soil column. However, an attempt was made to maintain the characteristic structure of the soil.

CAPILLARY CONDUCTIVITY OF THE SOILS

Each of the soils took up water from the cells before appreciable amounts of water commenced to flow through the column of soil. Calculations of capillary conductivities were made from data taken after a steady flow of water through the system was established. In the report by Richards and Wilson[5] a steady flow was assumed to exist when the amount of flow to and from the soil column differed by less than 1%. Because this relationship was not attained at low conductivities, those authors assumed that an insufficient period of time had elapsed for the establishment of steady flow.

The present work served to show that the rate of flow of water into and from the soil was never equal. For a given period of time, the amount of water flowing from the soil became a definite fraction of the amount of water flowing into the soil. After that the ratio of inflow to outflow remained constant. The establishment of this relationship

[5]See footnote 3.

was used by the writers as the criterion of steady flow. At that state of flow the difference between the values for inflow and outflow, divided by the time interval, gave, in most cases, a constant value of about 2.5×10^{-5} cc/sec. This seemed to indicate that water was lost from the system at a constant rate. The rate of loss varied from less than 1% to approximately 100% of the inflow. In computing the capillary conductivities of the soils the rate of inflow was used, because if water was lost from the system, the most likely source of loss was from the burette used for collecting the outflow of water from the soil.

Recorded in Table 1 are the capillary conductivities of the soils at different capillary tensions. These data are presented graphically in Fig. 1. The graphs of the figure were drawn using as ordinates the logarithms of the values for capillary conductivities which are shown in the last column of Table 1, and as abscissas the corresponding values for capillary tensions. At equal tensions the conductivity of peat A, which had been tilled for more than 20 years, was greater than was that of any of the other soils. Its conductivity was considerably greater than was that of the virgin soil taken from the surface foot of the same peat deposit. A comparison of the conductivities of the two virgin soils shows the one that was screened to have higher values at the higher tensions. At comparable tensions the screened soil did not differ greatly in conductivity from the soil that had been cultivated for two cropping seasons. The order of the magnitude of the capillary conductivities of the several soils suggests that particle size was an important factor in controlling the flow of water through the soils, the soils of finer texture having the greater capillary conductivities. One of the oustanding features of Fig. 1 is the relatively

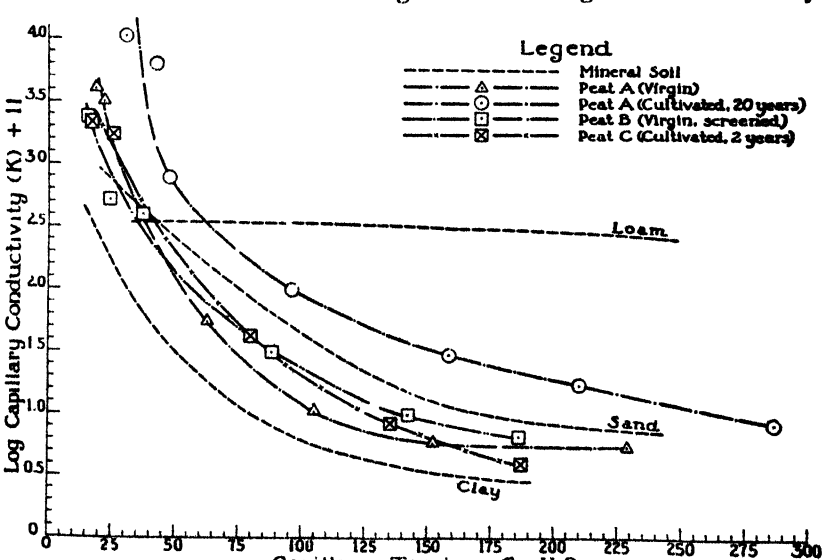

FIG. 1.—Capillary conductivity of peat and mineral soils at different capillary tensions.

high capillary conductivity of peat A, cultivated. The tendency of the graphs for the other peat soils to converge at the lower tensions indicates that, at those values, the soils did not differ greatly in the ability to conduct water.

TABLE 1.—*Capillary conductivity of water in peat soils at different capillary tensions.*

Date of record	Capillary tension, equivalent water column in cm	Capillary conductivity, seconds X 10^{11}	Log K+11
	Peat A (Virgin)		
Aug. 1	18.6	4,010	3.60
Aug. 19	22.0	3,120	3.49
Oct. 6	152.3	5.9	0.77
Oct. 22	104.8	10.4	1.02
Nov. 30	62.5	54.1	1.73
Dec. 23	228.9	5.4	0.73
	Peat A (Cultivated, 20 Years)		
Aug. 1	30.4	1,040	4.02
Aug. 19	42.6	632	3.80
Oct. 3	158.3	30	1.48
Oct. 22	95.7	99	2.00
Nov. 28	47.5	781	2.89
Dec. 11	210.2	17.3	1.24
Dec. 23	287.1	8.4	0.92
	Peat B (Virgin, Screened)		
Jan. 3	15.8	2,360	3.37
Jan. 16	36.8	399	2.60
Feb. 6	142.0	10	1.00
Mar. 10	23.6	525	2.72
Mar. 29	88.2	31.8	1.50
Apr. 19	186.3	6.7	0.83
	Peat C (Cultivated, 2 Years)		
Jan. 17	25.1	3,460	3.54
Feb. 5	135.1	8.4	0.92
Mar. 10	17.2	2,180	3.34
Mar. 26	79.4	42.8	1.63
Apr. 19	186.9	4.9	0.69

Graphs are also shown in Fig. 1 for three mineral soils, and they serve as a basis for comparing the capillary conductivities of organic and inorganic soils. The comparison seems admissible because essentially the same method of procedure was employed for measuring the capillary conductivities of the two types of soils. The graphs for the mineral soils were constructed from data reported by Richards.[6] An inspection of Fig. 1 reveals a similarity in the shape and the position of the graphs for the peat soils and the sandy and clay soils. The graph for the loam soil is distinctly different in character. The nature of the graph implies that the capillary conductivity of the loam soil is not materially affected by changes of considerable magnitude in capillary tension This quality may be associated with the texture of the loam soil.

[6]See footnote 4.

The graphs of Fig. 1 substantiate the conclusion drawn by Richards and Wilson[7] that at relatively low tensions the capillary conductivities of peat soils exceed those of mineral soils, and they suggest that at relatively high tensions the same order would hold for the finer-textured mineral soils.

MOISTURE CONTENT AND CONDUCTIVITY

At the conclusion of the measurements of capillary conductivity each soil was removed from the apparatus and the moisture content of the soil was determined. The percentages of moisture noted in the last column of Table 2 represent the amounts of water which were present in the soils at the time of the lowest observed conductivity measurements. Included in the table are similar values for the three mineral soils referred to in Fig. 1.

TABLE 2.—*Moisture content of soils at the lowest observed capillary conductivity.*

Soil	Capillary tension, equivalent water column in cm	Capillary conductivity seconds X 10^{11}	Moisture %, dry soil
Peat A (virgin)	229	5.4	209
Peat A (cultivated, 20 years)	287	8.4	148
Peat B (virgin, screened)	169	6.7	182
Peat C (cultivated, 2 years)	169	4.9	111
Greenville loam	597	72.7	15
Sandy Soil	243	7.0	5
Preston clay	149	3.3	42

An inspection of Table 2 shows that, at high tensions, the capillary conductivity in peat soil is low even though the moisture content is high. The highest capillary tensions used for the respective soils ranged from 169 to 287 cm of water and the corresponding moisture contents, expressed in terms of dry soil, ranged from 111 to 209%. It may be seen in Table 2 that, for both the peat and the mineral soils, the soil containing the highest percentage of moisture did not necessarily possess the greatest capillary conductivity The relation of the values shown in the table to the ability of the soils to supply water to growing plants is not known; nor is it known at the present time what differences in conductivity may be required to cause appreciable differences in plant response or cultural practices. It is felt, however, that the laboratory measurements of conductivity give a true indication of the relative moisture transmitting property of the soils tested.

SUMMARY

Studies were made of the capillary conductivity of water in four peat soils for varying capillary tensions. The conductivities of the soils were found to decrease rapidly and continuously with increasing values for capillary tension. To measure conductivities below the

[7]See footnote 3.

values recorded in this report would necessitate a modification of the apparatus employed in the work in order to avoid moisture losses.

An increase in the capillary conductivity of peat soil seems to accrue from prolonged cultivation owing to a type of structure resulting from cultural practices.

Certain comparisons are made between the capillary conductivity of peat and mineral soils and of the moisture content of the soils at low conductivity measurements. The conductivity of peat soil was found to be extremely low in the presence of relatively large amounts of moisture.

More information is needed before the significance of the conductivity values which are reported can be interpreted with respect to the capacity of the soils to supply water to growing plants.

THE ESTABLISHMENT OF LOW HOP CLOVER, *TRIFOLIUM PROCUMBENS*, AS AFFECTED BY TIME OF SEEDING AND GROWTH OF ASSOCIATED GRASS[1]

E. A. HOLLOWELL[2]

THE low hop clover (*Trifolium procumbens*) and the least hop clover (*T. dubium*) are winter annuals widely distributed throughout the southeastern states, although neither species is indigenous to this country. The least hop clover and to a less degree the low hop clover also occurs in many sections of the Pacific Northwest.

In the northern part of the southeastern states the low hop clover predominates, but in the southern part the least hop clover is more abundant. In between there is a wide transition zone where there is an intermingling of both species. When the low hop clover is introduced into the southern part of the United States, it is slightly more productive than the least hop clover, although on most soils it may not become the dominant species unless minerals are supplied.

Both species are valuable in pastures supplying early spring pasturage and increasing the fertility of the soil for the companion grass. If permitted to bloom, hop clovers produce an abundance of seed since they are self-fertile and self-pollinating and are tolerant of variable environments.

In many places the occurrence of either of the species is sporadic, being abundant in certain years and scarce in others. Since the seeds of these species germinate in the fall, the hazards in establishment are great as the very small seed must be near or on the soil surface when germinating. While it appears that hop clover is best adapted to a grass habitat, observations suggest that the competitive effect of the associated plants during the time of establishment of the young clover seedlings may be one of the factors determining their irregular occurrence. As a part of a life history study this experiment was designed to determine the effect of the height of growth of the associated grass and of the date of seeding on the stand establishment of hop clover and whether stands can be established in cultivated soil.

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Bureaus of Animal Industry and Dairy Industry, U. S. Dept. of Agriculture, and the Agricultural Experiment Stations of Kentucky, Missouri, North Carolina, Tennessee, and Mississippi, and the Georgia Coastal Plain Station. Received for publication April 13, 1938.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. This experiment was made possible through the cooperation of the following investigators to whom grateful acknowledgment is made: M. A. Hein, Division of Forage Crops and Diseases, Bureau of Plant Industry, Washington, D. C.; E. N. Fergus, Lexington, Ky.; R. E. Stitt, Piedmont Branch Experiment Station, Statesville, N. C.; E. M. Brown and J. M. Poehlman, Columbia, Mo.; J. L. Stephens, Tifton, Ga.; R. B. Carr, Iberia Livestock Experiment Station, Jeanerette, La.; L. R. Neel, Middle Tennessee Experiment Station, Columbia, Tenn.; and T. F. Akers, West Point, Miss.

METHOD OF PROCEDURE

Since the hop clover species (*T. procumbens* and *T. dubium*) are so similar in growth relationships only the low hop clover (*T. procumbens*) was used. It is believed that the results obtained from one will apply to the other. The experiment was begun in 1934 at Beltsville, Md.,[3] Statesville, N. C., Lexington, Ky., Columbia and Grain Valley, Mo., Tifton, Ga., Jeanerette, La., and Columbia, Tenn.

The plats were located in pastures at some places and elsewhere on established sod where areas covered with unclipped or non-grazed grass were selected. The height and density of the turf varied between places and in different years at the same place. A well-prepared, firm seedbed was made for the cultivated plats which were usually not adjacent to the seedings made on the sod.

Monthly plantings were made from September to March but at most places after the first year the late winter and early spring seedings were eliminated since they were generally unsatisfactory. Seedings were usually made from the first to the fifth of the month on square rod plats, on closely clipped grass turf, on unclipped or tall grass plats, and at certain locations on cultivated soil. During the first year the dates of seeding and the differential grass treatments were made on contiguous plats but later were randomized and replicated.

Seedings of the first year were made at the rate of 3 pounds per acre of 100% germinable inoculated seed, but were increased to 10 and 40 pounds per acre for the second and third years, respectively, in order to have more dense stands for recording contrasts.

Other related investigations have shown that these heavier rates of seeding did not approach the amount that is normally produced by good stands. All seedings were broadcast without subsequent treatment.

The grass on the closely clipped plats was cut from 1 to 2 inches in height and removed immediately before seeding and was generally kept clipped thereafter to simulate close grazing until growth ceased in the fall.

Records on height and density of the grass and stand and development of the clover were taken from seeding until the clover blossomed in the spring. At certain locations animals were allowed to graze the plats in the spring and elsewhere the clover was permitted to make full growth. At a few places the same plats were used during the succeeding years to determine whether the stands could be maintained.

Since this study was conducted at several different locations the results are grouped into two divisions according to the growth period of the grass with which the clover plantings were made.

SEEDINGS WITH NORTHERN GRASSES

The seedings at Beltsville, Md., Lexington, Ky., and Grain Valley, Mo., were made on pasture turf principally composed of Kentucky bluegrass (*Poa pratensis*); at Columbia, Mo., on an association of redtop (*Agrostis alba*), Canada bluegrass (*Poa compressa*), and Kentucky bluegrass; while at Statesville, N. C., orchard grass (*Dactylis glomerata*) was the dominant species intermixed with redtop (*Agrostis alba*), tall oat grass (*Arrhenatherum elatius*), timothy (*Phleum pratense*), Korean lespedeza (*Lespedeza stipulacea*), and common and Kobe lespedeza (*Lespedeza striata*). No seedings were made on cultivated soil at Beltsville, Lexington, and Grain Valley. Table 1 gives the results of this study. The results at different locations are not

[3]National Agricultural Research Center.

comparable since the various environmental factors differ. That more complete stands were obtained when the seedings were made in short than in the tall grass is significant. At all locations September or October seedings proved to be superior to the later ones.

At Beltsville during the first week of October 1935 a thick stand of volunteer hop clover was observed in closely cut plats of the September, October, and November 1934 seeding, indicating successful establishment under the close fall clipping practice.

The 1934 seeding at Lexington was grazed by sheep in the spring of 1935 and, as at Beltsville, the hop clover was kept closely grazed until the plants died. The grass on the closely clipped plats of the 1935 seedings was clipped early before the September seeding, but was not cut at later intervals. The grass made a heavy fall growth and this may have contributed to a reduction of the stands of clover. The 1936 seedings were on grass that was slightly thinner than the previous years, due to severe summer drought. The germination on all plats was relatively high this year. The clover plants growing with the uncut grass, however, were spindling, yellowish in color, while those with the short grass were short, thrifty, and of a normal color. In the spring of 1937 when the clover was blooming, the grass of the clipped plats was 2 to 4 inches shorter than that of the unclipped. These same plats were continued in the fall of 1937 with a volunteer seeding. All plats were clipped in late August to a height of 3 inches and in early October the short clipped plats of 1936 were clipped to a height of 1½ inches. In November 1937 the stands on the short clipped grass were 100%, while those on tall grass plats were 35 to 50%. In the clipped plats the plants were thrifty and a normal green while those of the unclipped plats were weak and yellowish in color and it is believed that these will not survive the winter This pasture was moderately grazed with sheep during the spring of 1937.

At Columbia, Mo., the differences between the stands on the clipped and unclipped plats of the 1935 seeding were not so wide as might be expected with more dense stand and fall growth of the grass. This condition of the grass undoubtedly resulted from the effects of successive years of drought. These plats were not grazed or cut thereby permitting a volunteer seeding. The volunteer seeding and hard seed of the previous seeding produced excellent stands in the fall of 1936, but the grass had been killed by the summer drought and no differences were apparent between the treatments. In contrast to Columbia, Mo., the 1936 seeding at Grain Valley was made on a very dense stand of grass which had not been grazed or clipped during the 1936 season. Volunteer seeding in the fall of 1937 was heavy and the plats are to be continued to determine whether stands may be maintained.

At Statesville the turf of the non-clipped grass plats was more dense in 1935 than in 1936. Late winter and early spring seedings at Statesville germinated and resulted in fair stands, which failed to make much growth or to reproduce. Stands from the September seeding were seriously reduced by an intense drought after a favorable period for germination. While the seedings on the cultivated soil failed to approach the same density of stands as those seeded with grass, the

TABLE 1.—*Estimated percentage stand and height of clover at blooming period of low hop clover (Trifolium procumbens) seeded on tall and short grass and cultivated soil at Beltsville, Md., Lexington, Ky., Statesville, N. C., Columbia, Mo., and Grain Valley, Mo., during the years 1934–1937.*

Treatment of plats	Date of seeding														Condition and density of grass at seeding date
	September		October		November		December		January		February		March		
	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	
	Beltsville, Md., 1934–35														
Clipped grass	70	7–9	70	7–9	70	7–9	0	—	0	—	0	—	0	—	Turf dense, uncut grass 7–9 inches high; considerable mature grass
Non-clipped grass	T*	—	T	—	T	—	0	—	0	—	0	—	0	—	
	Lexington, Ky., 1934–35														
Clipped grass	40	—	50	—	10	—	0	—	0	—	0	—	0	—	Turf very dense, uncut grass 8 inches high; much matted mature grass on all plats
Non-clipped grass	T	—	T	—	T	—	0	—	0	—	0	—	0	—	
	Statesville, N. C., 1934–35														
Clipped grass	5	6	50	6	60	6	50	6	50	4	50	2	50	2	Turf somewhat open, uncut grass 4–6 inches high
Non-clipped grass	5	6	10	6	10	6	5	6	50	4	50	2	50	2	
Cultivated soil	5	10	5	10	20	10	20	8	5	6	5	4	5	3	
	Beltsville, Md., 1935–36														
Clipped grass	90	—	90	—	25	—	0	—	0	—	0	—	0	—	Turf dense, uncut grass 4–6 inches high somewhat patchy because of light grazing
Non-clipped grass	25	—	25	—	T	—	0	—	0	—	0	—	0	—	

Lexington, Ky., 1935–36															
Clipped grass	50	4–6	50	4–6	50	2–4	50	2–4	50	2–4	95	0.5–1.5	95	0.5–1.5	Turf very dense, uncut grass 5–8 inches high, much mature grass
Non-clipped grass	T	—	T	—	T	—	T	—	T	—	T	—	T	—	
Statesville, N. C., 1935–36															
Clipped grass	50	—	50	—	0	—	0	—	0	—	0	—	0	—	Turf open, uncut grass 3–5 inches high; fall growing condition unfavorable
Non-clipped grass	30	—	50	—	0	—	0	—	0	—	0	—	0	—	
Columbia, Mo., 1935–36															
Clipped grass	75	—	90	—	25	—	T	—	T	—	T	—	0	—	Turf somewhat open, uncut grass 3–5 inches high
Non-clipped grass	30	—	75	—	5	—	T	—	T	—	T	—	0	—	
Cultivated soil	0	—	0	—	0	—	0	—	0	—	0	—	0	—	
Beltsville, Md., 1936–37															
Clipped grass	90	10	90	10	—	—	—	—	—	—	—	—	—	—	Turf dense, uncut grass 6–10 inches high
Non-clipped grass	T	—	T	—	—	—	—	—	—	—	—	—	—	—	
Lexington, Ky., 1936–37															
Clipped grass	99	5–6	76	5–7	—	—	—	—	—	—	—	—	—	—	Turf dense, uncut grass shorter than normal, 4–6 inches high
Non-clipped grass	26	5–7	12	5–7	—	—	—	—	—	—	—	—	—	—	
Grain Valley, Mo., 1936–37															
Clipped grass	10	6	T	—	—	—	—	—	—	—	—	—	—	—	Turf very dense, uncut grass 6–10 inches high; much mature grass not cut or grazed in 1936
Non-clipped grass	T	—	T	—	—	—	—	—	—	—	—	—	—	—	

*Trace.

growth of the plants was greater. In 1935 the growth of the companion grass was short due to drought, making the height of the grass on both the clipped and non-clipped plats the same, and in the spring of 1937 all plats had nearly perfect stands, though not quite so dense on the non-clipped as on the clipped plats.

SEEDING WITH SOUTHERN GRASSES

Bermuda grass (*Cynodon dactylon*) was the companion of the seedings made at Tifton in 1934 and 1936, and at Columbia, Tenn., while at Jeanerette seedings were made in an association of Bermuda grass, foxtail (*Setaria* sp.), and vasey grass (*Paspalum Urvillei*). The 1935 seedings at Tifton were with carpet grass (*Axonopus compressus*). In contrast with Kentucky bluegrass, Bermuda grass does not form a dense mat at the surface of the soil, particularly in soils at the lower fertility levels. Carpet grass, however, does form a thick ground cover. The results of these plantings are given in Table 2.

The results at Tifton are the most comprehensive of those where planting was made with the southern grasses Early seedings under all conditions were the least successful. Fall droughts interspersed by short wet periods and accompanied by temperatures conducive to the rapid evaporation of the surface soil moisture resulted in the death of the young seedlings. Regardless of the seeding date, plantings made in cultivated soil failed to produce good stands. While partial stands on sod were obtained for all seeding dates, the February and March plantings were the least successful and resulted in meager growth. The clover seedings on the non-clipped Bermuda grass plats generally produced better stands than those on the clipped turf. In contrast to the results with seedings on Bermuda grass the seedings on carpet grass produced the best stands under the clipped grass treatment. The hop clover growing in the 1934–35 plats was allowed to seed and volunteer in the fall of 1935 without an additional seeding. All the plats were clipped according to the clipping schedule of 1934. The stands in the spring of 1936 for the original September, October, November, and December 1934 seedings on both clipped and non-clipped plats varied from 50 to 100%. A similar treatment was given in 1936 as in 1935, resulting in a more dense stand of clover on the clipped than on the non-clipped plats. The stand of Bermuda grass on these plats was decidedly thicker than during the previous years.

At Columbia, Tenn., the early seedings produced good stands on both the clipped and non-clipped grass, while the seedings made on cultivated soil produced poorer stands than those seeded with grass.

At Jeanerette the 1934 September seeding was delayed until the latter part of the month. The turf composed principally of Bermuda grass was somewhat open even though casual observation would indicate a dense cover. The results of the 1935 planting were similar to those of the previous year as shown in Table 2. Only at Jeanerette have any of the seedings on cultivated soil equalled the seedings made on turf.

The experiment at West Point, Miss., in 1934 unfortunately was located in a wet situation resulting in a failure. In 1936 excellent

stands were obtained in a seeding on both clipped and non-clipped grass at seeding dates of September 15 and October 15, respectively. An excellent volunteer stand occupied all of these plats in November 1937. The companion grass, principally Bermuda with some dallis grass (*Paspalum dilatatum*), did not make a dense turf.

DISCUSSION AND CONCLUSIONS

In interpreting the results consideration must be given to the ecological factors of light, soil moisture and temperature, and soil fertility as related to the germination and development of the hop clover and the growth habits of the companion grass. Since the northern and southern grasses differ so widely it seems advisable to relate the discussion to the data as presented.

The results at Beltsville, Md., Lexington, Ky., Statesville, N. C., and Columbia and Grain Valley, Mo., clearly indicate that the tall grass inhibits the successful establishment of hop clover regardless of date of seeding. With the advent of cool, moist weather the northern grasses begin rapid growth spreading vegetatively and developing a dense turf thus competing with the seedling development of hop clover. Climatological data for the different years indicate that under such environments soil moisture has not been the limiting factor nor has soil temperature, since stands were established on the clipped plats. The lack of sufficient light is believed to be the principal reason for failures. In a few places, however, thin stands have been obtained in tall grass with the development of spindling plants which died during winter.

The association of hop clover with grass appears to be beneficial to establishment and survival of the clover, for at Statesville the stands in the cultivated soil plats were much thinner than those planted with grass and at Columbia, Mo., all seedings on the cultivated soil failed in stand establishment. Observations indicate that the grass is beneficial in reducing the hazard of rapid evaporation with subsequent drying of the soil surface thereby influencing the germination or decreasing the mortality of the clover seedlings in their early establishment. The results also clearly indicate that in the latitude where the experiments were conducted September and October seedings will give the most nearly complete stands. While stands from December, January, and February seedings have been obtained during certain favorable years, spring growth of the plants has not been significant and reproduction has failed. It has also been shown that increased rates of seeding to offset the hazards of unfavorable conditions when the initial stands are being established may be a necessary prerequisite to successful establishment of a stand and the development of a seed equilibrium.

When hop clover was planted with southern grass the results present less conclusive evidence of the relationship of the competitive effect of grass on stand establishment. With most all seedings on Bermuda grass, just as good or better stands were obtained in nonclipped as in clipped grass. The results with carpet grass for one year at Tifton show superior stands on the clipped plats. These differences may be attributed to differences in growth habits of these grasses.

TABLE 2.—*Estimated percentage stand and height at blooming period of low hop clover (Trifolium procumbens) seeded on tall and short grass and cultivated soil at Tifton, Ga., Columbia, Tenn., and Jeanerette, La., during the years 1934–1937.*

Treatment of plats	Date of seeding														Condition and density of grass at seeding date
	September		October		November		December		January		February		March		
	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	
Tifton, Ga., 1934–35															
Clipped grass	18	1–4	20	4–6	13	2–4	30	2–4	23	1–2	15	1–2	0	—	Bermuda grass thick stand uncut grass 6–8 in. in height; turf open at soil surface
Non-clipped grass	25	4–10	45	4–10	20	4–8	75	6–10	67	4–6	23	1–2	13	—*	
Cultivated soil	10	1–4	20	2–6	30	2–4	30	2–3	15	1	18	1–2	0	—	
Columbia, Tenn., 1934–35															
Clipped grass	75	10	85	10	15	8	15	8	T	—	T	—	T	—	Bermuda grass thick stand, uncut grass 4–6 in. in height; turf open at soil surface
Non-clipped grass	75	10	80	10	15	8	15	8	T	—	T	—	T	—	
Cultivated soil	40	9	15	7	5	—	T	—	T	—	T	—	T	—	
Jeanerette, La., 1934–35															
Clipped grass	70†	8–10	—	—	50	8–10	—	—	1	—	1	—	1	—	Bermuda and vasey grass, uncut grass 6–12 in. in height; thick stand, turf open at soil surface
Non-clipped grass	50	10–14	—	—	50	8–10	—	—	1	—	1	—	1	—	
Cultivated soil	75	4–8	—	—	50	4–6	—	—	33	6–8	1	—	1	—	

							Tifton, Ga., 1935–36								
Clipped grass	10	6	60	8	75	8	60	8	20	8	5	6	5	6	Carpet grass thick stand, 4–6 in. in height; thick ground cover
Non-clipped grass	10	6	20	6	40	6–8	60	6–8	50	6–8	5	6	T	—	
							Jeanerette, La., 1935–36‡								
Clipped grass	—	—	70	3	75	4	75	4	—	—	Failed		Failed		Turf open, uncut grass from 6–12 in. in height; mostly Bermuda with foxtail and vasey
Non-clipped grass	—	—	80	4	85	5	85	6	—	—	—	—	—	—	
Cultivated soil	—	—	70	2	75	2	70	3	—	—	—	—	—	—	
							Tifton, Ga., 1936–37								
Clipped grass	10	6	20	6	40	8	60	8	50	8	5	6	0	—	Bermuda grass, thick stand, uncut grass 6–8 in. in height; turf open at soil surface
Non-clipped grass	10	6	60	10	75	10	60	8	20	8	0	—	5	6	

*Discarded on account of volunteer white clover.
†Seedings made Sept. 27, 1934.
‡Seedings made on Oct. 17, Nov. 2, and Nov. 27, respectively

The stems developed from the spreading under-ground rhizomes of Bermuda grass do not tiller where they emerge through the soil surface. This results in an openness in the turf at the surface of the soil.

In contrast to the Bermuda grass, carpet grass spreads vegetatively by creeping stems which make a dense tight mat over the soil surface. It is believed that this growth habit is responsible for the differences in behavior of the hop clover seedings as related to clipped and non-clipped treatments.

The results at Tifton clearly indicate that late fall is the preferable time for seeding. At Jeanerette in 1934 the late September seeding was superior to the November seeding. In the southern part of this region soil moisture and temperature appear to be important ecological factors in the establishment of the clover. When seeded in early fall the grasses are still competing vigorously, both soil and atmospheric temperatures are relatively high, and periods of dry weather are not uncommon. The interspersing of short rainy periods with a rapid drying of the soil surface and dry weather are fatal to germinating seed and young seedlings. As the fall progresses with a lowering of temperature the southern grasses become dormant, reducing their demand for moisture and, by shading, conserve it at the soil surface by reducing evaporation. This protection afforded by the non-clipped companion grass favors the clover since it is not of sufficient density to reduce the light necessary for its establishment. This interaction of the ecological relationships is evident from the planting at Columbia, Tenn., where at a more northern latitude the early plantings produced the best stands.

As the fertility of the soil increases supporting a more dense stand and growth of grass or cover at the soil surface, fall clipping or close grazing may be expected to facilitate the establishment of hop clover as was observed at Tifton on the 1936 volunteer plats. The results at Tifton also indicate that a short dense cover of carpet grass will protect the developing clover seedlings similar to a less dense cover but taller Bermuda grass.

The establishment of good stands on cultivated soil at Jeanerette and the failure at other places in the southern states appears to be the result of a favorable soil relationship. The heavy clay soils at Jeanerette are low lying, retentive of moisture, and higher in organic matter than the other soils where seedings were made without grass as a companion plant.

Observations at other localities have shown that the same relationships exist with other Trifolium species such as Persian clover (*Trifolium resupinatum*) and white clover (*Trifolium repens*) where the latter behaves as a winter annual.

THE RELATION OF LIGNIFICATION OF THE OUTER GLUME TO RESISTANCE TO SHATTERING IN WHEAT[1]

O. A. VOGEL[2]

THE problem of shattering of wheat is of greater importance to the wheat industry in the Pacific Northwest than in any other major wheat-producing area of the United States. In this area the harvest season covers a period of two to three months and a large portion of the grain often stands in the field two or three weeks after maturity. During this extended harvest season the standing grain is frequently subjected to hot winds of high velocity and low relative humidity, causing heavy losses of grain from shattering. Losses of 5 to 15% have been frequently observed among several of the commercial varities in the Palouse and neighboring areas during recent years. Other varieties having greater resistance to shattering but growing under similar conditions lost comparatively little or no grain. However, the more resistant varieties are sometimes difficult to thresh and thereby produce an excess of cracked kernels and unthreshed single-grained tip spikelets, both of which are discriminated against in the grain trade.

In the present wheat improvement program attempts are being made to select strains and hybrids that possess enough resistance to prevent much of the shattering in the field and still thresh reasonably easy. In the course of this work it has become obvious that a better understanding of the nature of resistance to shattering is needed. This need has led to a study of the structural details at the breaking points in the basal portions of the outer glumes of the wheat spikelet. The outer glumes were chosen for this study because, from the standpoint of resistance to shattering, their primary function seems to be to help hold the other flowering parts in place.

MATERIAL AND METHODS

The four central spikelets from each of several typical heads of several varieties of wheat representing varying degrees of resistance to shattering were collected at six stages of growth, namely, late boot; flowering; early, medium, and stiff dough stages; and at maturity. The grains were carefully removed leaving intact the lemmas and outer glumes. The remaining portion of each spikelet of the five immature stages was killed in alcohol-formalin-acetic acid solution, dehydrated,

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[2]Assistant Agronomist, Division of Cereal Crops and Diseases. The writer is grateful for the use of the equipment of the Department of Botany, State College of Washington, and for the interest and many helpful suggestions of Dr. H. F. Clements, formerly Associate Professor, and Dr. Hanna A. Aase, Associate Professor of that Department, and the advice and comments of Dr. E. F. Gaines, Cerealist, of the Agronomy Department.

and infiltrated with paraffin. Those of the mature stage were placed directly into paraffin at 175° to 200° C for approximately 1 hour.

To determine the location at which the break occurs, the outer glumes of some of the mature spikelets were bent back enough to break as much as possible of the tissue at the breaking point without severing completely the two parts.

Considerable difficulty was experienced in cutting the material into desirably thin sections. Material gathered in the boot and flowering stages was cut successfully in 16-micron sections with a rotatory microtome. The older material, because of its brittle nature, necessitated cutting at thicknesses of 40 and 60 microns with a sliding microtome.

Both cross and longitudinal sections were cut through the basal portions of the glumes. The longitudinal sections were cut parallel to the broad side of the spikelet. The sections from each glume were arranged serially on from one to three slides.

Albumin was used to fix the sections on slides from material in the boot and heading stages, but LePage's glue with potassium bichromate was more satisfactory for the later stages. The sections were then stained with malachite green and Bismarck brown and mounted in balsam.

EXPERIMENTAL RESULTS

It appeared desirable to determine first the location at which the glume breaks from the rachis. This is shown by the two longitudinal sections in Fig. 1, A and B, which were taken from a mature glume of the variety Sherman (C. I. 4430). Measurements of these sections and similar measurements of other sections indicate that the break usually occurred between 0.1 and 0.2 mm above the inside base of the glume.

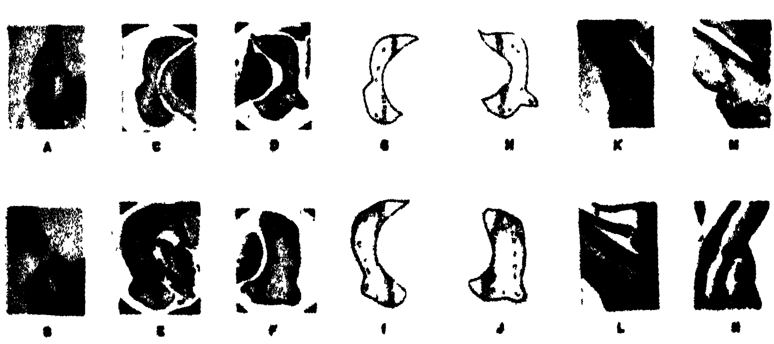

FIG. 1.—Photomicrographs of longitudinal and cross sections of the basal portion of wheat glumes. A, B, longitudinal sections of mature glume of Sherman wheat showing the breaking point; C, D, cross sections of 1st and 2d glumes of a spikelet of White Odessa (C. I. 4651); E, F, cross sections of 1st and 2d glumes of a spikelet of White Odessa (C. I. 4655); G, H, same as C and D with lignified areas stippled; I, J, same as E and F with lignified areas stippled; K, longitudinal section of Sherman at early dough stage of maturity; L, longitudinal section of White Odessa (C. I. 4655) at early dough stage of maturity; M, longitudinal section showing buckling of outer epidermis at the breaking point; and N, longitudinal section of mature glume of White Odessa (C. I. 4655).

Cross sections taken from the region at which the glume breaks were studied next. Sections C and D of Fig. 1 are from the breaking points of each of the two outer glumes of a spikelet of White Odessa (C. I. 4651) in the medium-late dough stage of growth. Similarly, sections E and F are from White Odessa (C. I. 4655). These represent varieties very susceptible and very resistant, respectively, to shattering. The lignified tissues are less distinct in the photomicrographs than under the microscope so sections C, D, E, and F are shown in outline in G, H, I, and J, respectively, with the lignified tissues stippled.

It should be noted that the first and second glumes of the same spikelet have a different pattern. Consequently, in order to compare one variety with another properly corresponding glumes of each variety must be used.

It is probable from the cross sections that, insofar as the outer glumes are concerned, the greater shattering resistance of White Odessa (C. I. 4655) is due to greater thickness and more lignified tissue. Furthermore, the smaller proportion of lignified tissue in the first glume (sections G and I) apparently accounts for this glume being usually more easily broken from the spikelet.

The relative proportion of lignified tissue in the basal portion of the outer glumes of 11 varieties of common wheat (*Triticum vulgare*) and 1 of emmer (*T. dicoccum*), compared with the 2 strains of White Odessa as standards, is shown in Table 1. A direct correlation was found between the relative proportion of lignified tissue and the shattering resistance class among the varieties tested. However, when the difference in lodging resistance was small as, for example, that between Fortyfold and its somewhat more resistant selection Golden, possible differences in lignified tissue were obscured by the variability between individual spikelets. A similar difficulty was encountered in comparing Kharkof with the somewhat less resistant variety Sherman. Further efforts to measure relatively small differ-

TABLE 1.—*Shattering resistance and relative lignification of the basal portion of the glumes in 11 varieties of common wheat and 1 of emmer.*

Variety	C.I. No.	Shattering resistance	Lignification
		Common Wheat	
Garnet	8181	Very susceptible	Very slight
White Odessa	4651	Susceptible	Slight (Fig. I, G, H)
Fortyfold	6176	Susceptible	Slight (Fig. I, G, H)
Mosida	6688	Susceptible	Slight (Fig. I, G, H)
Golden	10063	Slightly susceptible	Slight (Fig. I, G, H)
Sherman	4430	Slightly resistant	Slight to intermediate
Kharkof	1442	Resistant	Intermediate
Turkey	6175	Resistant	Intermediate
Ridit	6703	Resistant	Intermediate
Triplet	5408	Resistant	Intermediate
White Odessa	4655	Very resistant	Heavy (Fig. I, I, J)
		Emmer	
Emmer	4013	Extremely resistant	Very heavy (half to three-fourths)

MEASURING THE DIAMETER OF THE COTTON FIBER[1]

JERRY H. MOORE[2]

CERTAIN physical properties of the cotton fiber are of importance to cotton breeders and spinners. For many years length of staple has been considered one of the most important properties affecting the market and spinning value of cottons. In more recent years, strength, diameter, drag or clinging power, and unit fiber weight per inch have been measured in cotton varieties and their influence upon spinning quality noted.

In our American upland varieties of cotton, diameter of fiber is a property which appears to influence spinning value; that is, a smaller diameter is apparently associated with an increasing yarn strength. In an investigation of the relation of diameter and other physical properties of the cotton fiber to spinning value in seven American upland strains, Moore (6)[3] found that a decreasing fiber diameter was associated with an increasing yarn strength. In investigations of the spinning value of 14 samples of Egyptian cotton, Barritt (1) concluded, "that the selection of cotton for staple and low diameter would appear to offer everything the spinner can reasonably ask and all the grower can hope to supply."

The writer has noted during recent years that diameter is an inherited property, and other investigators state that this property depends mostly upon heredity. Different seasonal conditions may, of course, cause fluctuations in fiber diameter, but we can expect cottons differing significantly in fiber diameter to show these relative differences consistently in successive seasonal progenies. Since fiber diameter appears to be a fairly stable genetic property which can be selected and perpetuated and since it influences the spinning value of cottons it seems that breeders and other cotton investigators should select for this property in a program of cotton improvement.

Green, uncollapsed mature cotton fibers are tubular in form as shown by transverse sections in Fig. 1, B. Upon drying, however, such fibers assume irregular forms as indicated in Fig. 1, C. Measuring the diameter of the collapsed fibers is not very practicable, and the investigator could not always depend upon measurements of green material for the necessary data. The most practicable method of measuring fiber diameter consists of mercerization with a sodium hydroxide solution to restore the fiber to a roughly cylindrical form as illustrated in Fig. 1, A.

The object of this investigation is to note the relation of green, uncollapsed diameter to mercerized diameter and to make recommendations concerning the measurement of this property.

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[1]Published with the approval of the Director as Technical Paper No. 103 of the North Carolina Agricultural Experiment Station, Raleigh, N. C. Received for publication March 12, 1938.

[2]Cotton Technologist.

[3]Figures in parenthesis refer to "Literature Cited", p. 609.

REVIEW OF LITERATURE

Calvert and Harland (3) thoroughly mercerized mature cotton fibers in an 18% solution of sodium hydroxide, then washed, dried, and mounted them in liquid paraffin on a slide, taking care to arrange the hairs approximately parallel. They then moved the slide across the microscopic field of view and drew a line across the middle of each fiber to indicate the width. Using a magnification of 1,200 diameters, they drew the lines with the aid of a *camera lucida* and measured

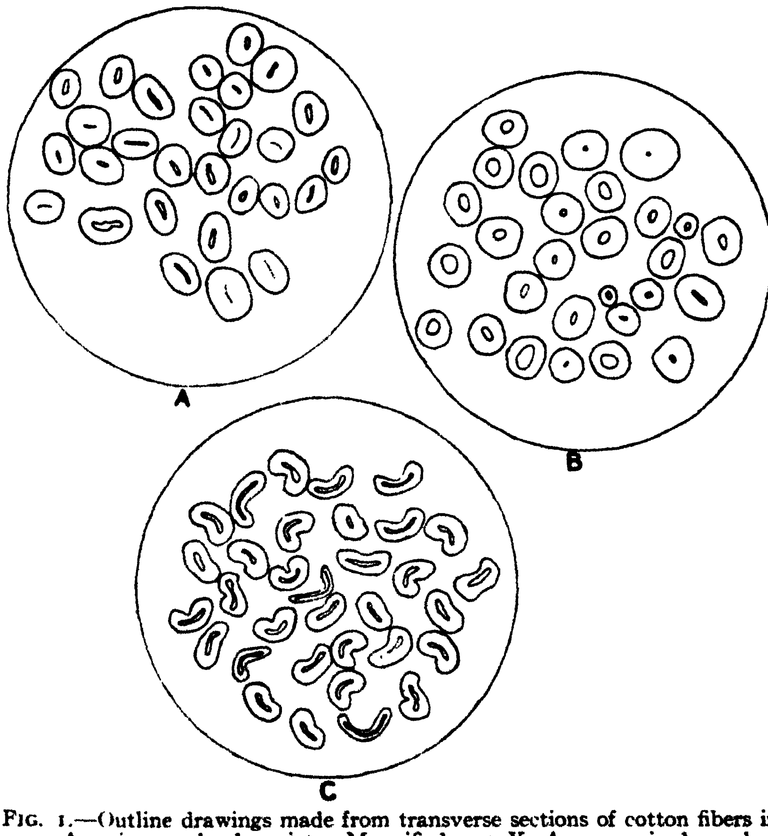

FIG. 1.—Outline drawings made from transverse sections of cotton fibers in an American upland variety. Magnified *220* X. A, mercerized, washed with water, and air-dried; B, green uncollapsed fibers 54 days of age from date when bloom appeared; C, collapsed, air-dried fibers.

them in millimeters. These investigators measured the mercerized diameter in 35 cottons covering a wide range and found the whole range of cottons to be comprised between the limits 11.9 and 20.2 microns, namely, between the finest Sea Island and coarse Peruvian.

Calvert and Summers (4) investigated the relation of the mercerized to the unmercerized hair width in 38 world cottons and found the ratio of the former to the latter to be approximately 0.8. They also noted the ratio of mercerized fiber width to uncollapsed fiber width in one Egyptian and one American strain of cotton and found the ratios to be, respectively, 0.72 and 0.62.[4]

[4]Ratios were calculated by the writer.

MATERIALS AND METHODS

Seven strains of American upland varieties (*Gossypium hirsutum* L) which had previously shown significant differences in fiber diameter were grown on the North Carolina State College farm during 1937 under similar environmental conditions.

Fresh blooms of each strain were tagged daily for several days with dated tags. When bolls from the dated flowers were just ready to open and 54 days old (from the date of blooming), they were picked, dissected, and then immediately put into a solution of 4 cc acetic acid, 8 cc formalin, and 82 cc of 70% ethyl alcohol to kill, fix, and preserve. Microscopic observation showed no apparent distortion of the pickled fibers. All the bolls preserved from the strains bloomed on the same day. Only one boll from a plant was placed in a jar, which was numbered to correspond with the plant number and name of strain. Eight to 10 bolls from as many plants of each strain were preserved for the observations.

In the laboratory, the green cotton fibers from a boll 54 days old were washed thoroughly in water to remove the fixative solution. Then approximately 100 uncollapsed fibers from this sample were taken at random under water and arranged approximately parallel on a wide slide. Water was added and a cover slip put on. Through the aid of a micro-projector apparatus and a mechanical stage, the diameter of the middle portion of each fiber was drawn by making a straight line as nearly as possible at right angles to the longitudinal boundaries of the fiber. Measurements have indicated that the width at the middle of the fiber length represents fairly accurately the average diameter of an entire fiber. By repeating this procedure a second lot of 100 fibers was measured in the boll sample, making a total of 200 measurements. A magnification of 380X was used in marking the diameter lines. The lines were measured to the nearest 0.5 mm with a millimeter rule. The average diameter of each sample was then calculated in millimeters and converted to the actual diameter in microns. The diameter of uncollapsed fibers was measured in three bolls from three plants of each cotton strain.

Some of the washed, uncollapsed fibers from each boll used above were exposed to the air at room temperature. Such exposure caused them to collapse and assume the morphological shape of normal field material. A composite sample was made from the collapsed fibers in the three bolls of each strain. Each composite sample was then mercerized thoroughly in an 18% solution of sodium hydroxide, washed thoroughly in water, and dried at room temperatures. One hundred fibers were then taken at random and mounted approximatey parallel to one another on a wide slide. Common mineral oil was added and a cover slip applied. Diameter measurements were then drawn and calculated as described in the preceding paragraph. A total of 400 measurements were made in each mercerized sample.

In order to obtain satisfactory transverse sections of cotton fibers with a minimum of distortion, the writer has tried several methods and over a period of 10 years has found the gelatin method to be the most satisfactory for general morphological outlines. This method has been previously described in its main details by Clegg and Harland

(5). The writer has used the method described by them with some modifications. A description of the method is given below.

Take a bundle of normal fibers, comb out the loose ones, pull and lap so as to have a bundle of several hundred fibers approximately parallel to one another. Cut a small window about ½ by ½ inch in a piece of cardboard about 1 by 1 inch. Cement the ends of the bundle on this cardboard with a fairly thin solution of collodion or any other cementing material which will not dissolve in water. A frame made from thin wood or wire is preferable to the cardboard frame. In some cases the ends of the fiber bundle may be held with a small paper clip at each end and the frame omitted. Carry the frame through alcohol to water in order to avoid air bubbles.

The material is next put in hot, concentrated gelatin (plain gelatin), which is kept hot for several hours at about 60° C. It is necessary to use gelatin in very high concentrations. When the frame is taken out of the solution there is a coating of gelatin surrounding the fibers. This is allowed to dry on the outside or immersed for a brief period in very cold water and the whole submerged in a solution of 95% ethyl alcohol and 5% commercial formaldehyde. The gelatin matrix can be built to the desired size by repeated dipping in the gelatin solution if the matrix is partially hardened in the formaldehyde-alcohol solution before each dipping. The material is hardened for 12 to 24 hours in the formaldehyde-alcohol solution and then the frame is cut and removed leaving the fibers in a hardened matrix which is transferred for final hardening to absolute ethyl alcohol or butyl alcohol for a period of 12 to 24 hours.

If the gelatin matrix has been built up to a large enough size, the cotton hairs are ready for sectioning. If the matrix surrounding the fibers is quite small, then it should be imbedded in paraffin which will act as a necessary support in cutting the hairs, which is done with a sliding microtome. During the sectioning process, it is necessary to have the edge of the long, very sharp knife set almost parallel with the matrix block in order to obtain a long, gradual cutting stroke, and the vertical angle of the knife should be about 15°. During the process the material is softened with 95% ethyl alcohol if too hard. If the gelatin is not excessively hard, the sections may be cut without wetting. In some cases sections can be cut to 5 μ in thickness, but usually it is preferable to limit the thickness to a minimum of 10 μ. The gelatin sections are unrolled in water on a glass slide, the water is allowed to evaporate, a drop of glycerine jelly added, and a cover slip applied.

The writer has easily obtained large gelatin blocks containing the cotton hairs in the following manner: Allow the first coat of gelatin covering the bundle of hairs to harden in the cold air. Place this matrix in a small paper cylinder about ½ inch in diameter and 1½ inches long, open at the top and closed at the bottom. Pour hot, concentrated gelatin into the cylinder, orient the matrix within, cool, and harden in the usual way. The paper may then be removed with the fingers and a sharp knife.

Green, uncollapsed fibers are carried from the fixative through water to gelatin, and thereafter the procedure is exactly like that followed in imbedding normal, collapsed hairs. Washed and dried, mercerized hairs are prepared for cutting according to the method just described for normal hairs.

EXPERIMENTAL RESULTS

The diameter of the uncollapsed fibers and its relation to that of the air-dried, mercerized fibers are contained in Table 1. The simple

correlation of uncollapsed diameter with mercerized diameter amounts to 0.95, which is very significant and quite satisfactory. It is likely that a substantial increase in the number of observations would give a correlation value somewhat nearer 1.00. The ratio of mercerized diameter to uncollapsed diameter in the seven strains is fairly uniform, the lowest being 0.623 and the highest 0.665, while the average ratio is 0.643. Thus, the close relationship of uncollapsed diameter with mercerized diameter, as shown in Table 1, indicates that the investigator can safely use the mercerized diameter for obtaining relative diameter differences in cotton varieties.

TABLE 1.—*The relation of mercerized, water-washed, air-dried fiber diameter to the diameter of uncollapsed, green fibers in seven strains of American upland cotton (crop of 1937).*

Cotton strains	Fiber diameter in microns		Ratio of mercerized to uncollapsed fiber diameter	No. of plants and bolls observed in each strain*	No. of diameter measurements	
	Mercerized fibers*	Uncollapsed fibers*			Mercerized fibers	Uncollapsed fibers
Acala 4067..........	14.47	23.22	0.623	3	400	600
Coker–Cleveland 884–4............	15.03	23.18	0.648	3	400	600
Mexican 128.........	15.31	24.46	0.626	3	400	600
Rowden 40..........	15.84	25.00	0.634	3	400	600
Rowden 2088........	16.24	25.42	0.639	3	400	600
Mexican 87–8.	17.11	25.75	0.665	3	400	600
Farm Relief No. 1....	17.20	26.09	0.659	3	400	600
Average	15.886	24.731	0.643			

Correlation of mercerized with uncollapsed fiber diameter = 0.95 (highly significant)

*The diameter values probably do not accurately represent the actual values for the seven strains since only three plants were observed in each strain.

Transverse sections of normal, uncollapsed, and mercerized cotton hairs were cut in gelatin and their outlines drawn with the aid of a micro-projector. The drawings are shown in Fig. 1. Observation of the figure shows that the uncollapsed, green sections are approximately circular and that the mercerized sections are somewhat less circular. Sections of normal, collapsed hairs are, however, usually very irregular in general outline, which seldom shows much resemblance to the circular form of the uncollapsed fibers in the cotton boll. The contrast indicates the difficulty of measuring the true diameter from normal, collapsed hairs.

Barritt (2) describes a method for measuring the diameter of collapsed hairs. By his method width and thickness of the hair are measured from a longitudianl view and the sum of the two measurements is divided by two to obtain the approximate diameter. The writer has tried this method and has found considerable error involved. The measurements are also doubled. The writer also made perimeter measurements with the aid of a planimeter or dividers on

transverse sections of normal, collapsed hairs, and using the formula Perimeter/3.1416, calculated the diameter. Such measurements are very tedious and subject to considerable error. The writer has obtained satisfactory and consistent results for a period of 10 years by measuring either the uncollapsed diameter or the mercerized diameter, and has obtained relatively accurate data with a minimum of trouble.

SUMMARY AND CONCLUSIONS

The diameter of uncollapsed and mercerized fibers was measured in seven strains of American upland cotton and the correlation values and ratios calculated.

Methods are described for measuring the uncollapsed and mercerized fiber diameter. The gelatin method of sectioning cotton fibers is described and transverse sections of uncollapsed, normal collapsed, and mercerized fibers are shown.

The correlation of uncollapsed with mercerized diameter amounted to the very significant value of 0.95, the ratio of mercerized to uncollapsed diameter in the seven cotton strains ranged from 0.623 to 0.665, and the average ratio was 0.643.

The diameter of cotton fibers can be measured most easily in uncollapsed material or in mercerized samples. The cotton breeder can determine the fiber diameter of cotton strains or individual plants by using bolls just before they open or bolls about 29 days of age from the date of blooming. Material from earlier boll stages may be used, but the fibers from the younger bolls are rather delicate and hard to arrange on the slide. For general use in diameter measurements, the diameter can be most practicably determined in mercerized samples. Usually 200 preliminary observations in each mercerized sample will be sufficient to show a significant difference of about 0.75μ, and indicated differences in diameter of the promising strains can be checked by making 200 additional observations in each cotton strain. The standard error and the analysis of variance are useful in estimating the significance of differences in this property, but they are certainly not infallible and the investigator should depend to a considerable extent upon observation and experience when interpreting the results.

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RELATION OF SOME PLANT CHARACTERS TO YIELD IN WINTER WHEAT[1]

H. H. LAUDE[2]

THE relation of plant characters to yield in winter wheat might be considered from the viewpoint of the relation of characters to the maximum yield, that is, to yield under optimum conditions. Probably certain plant characters are related to the potential capacity of a variety to yield or to produce grain, e.g., varieties of wheat that require a long season in which to mature probably have a higher potential possibility for yield than those that mature in a short time. Also the potential capacity to produce grain may be greater for tall than for short varieties, for plants with wide leaves than for those with narrow leaves, etc.

Another view of the question is the relation of changes in plant characters corresponding to differences in yield of a crop such as wheat when it is grown in sub-optimal conditions. This approach has much greater practical and probably greater technical importance than the former since nearly all, if not all, wheat is grown in sub-optimal environment. The chief problem is the manner in which the plant adjusts itself to the more or less unfavorable conditions in which it is growing and its capacity to survive adversity.

It is believed to be axiomatic that a plant always does the best that is possible with the conditions that surround it. Also it may be considered that the protoplasm is a sensitive measure of environmental conditions. The yield of the crop may be looked upon then as an exact measure or a final integration of all ecological conditions that have prevailed throughout the life of the plant.

Under the influence of the particular ecological conditions surrounding the plant, its physiological activity is modified so as best to meet those conditions. In some cases the rate of leaf growth may be retarded, in others the extent of tillering may be reduced, in still others the size of the head may be limited, again fertilization of the florets may be interferred with or perhaps the amount of translocation to the seed may be limited.

Numerous ecological factors might be mentioned as possible causes for the modification of physiological activity which in turn may result in a modification of some morphological feature of the plant. On the assumption that yield is a measure of all ecological conditions and that these conditions modify morphological features of the plant, it appears reasonable to assume that relationships may exist between morphological features and yield. Evidently these relationships cannot be simple since there are numerous ecological factors involved and their effects upon the plant may be expressed in many ways. The environmental factors may exert an influence on stand, on rate of growth, time of tillering, extent of tillering, time of heading, num-

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[2]Agronomist.

ber of heads per plant or per area, weight of grain per head, number of kernels per head, time of ripening, height of plant, test weight, weight per 1,000 kernels, or the ecological condition may be expressed in winter injury, leaf rust, stem rust, loose smut, bunt, septoria or other diseases, in damage by Hessian fly, chinch bugs, or other insects, in drought injury, and perhaps in other ways.

Although these and perhaps many other ecological factors have a definite influence on the physiological activity of the plant, their relative importance varies greatly from field to field, from year to year, and among varieties. The complexity of the problem of measuring the specific effect of ecological factors is at once apparent. Ultimately such effects should be measured, that is, it should be known how much reduction in yield need be expected due to a certain degree of winter injury, how much due to a given amount of Hessian fly damage, how much to a moderate infection of leaf rust, etc. It is desirable to know also what yield can be expected in a certain field if the number of heads per plant is low, or medium, or high, or how the yield will be influenced if soil moisture is insufficient, say from March 10 to April 20, and many other similar questions.

As a preliminary plan it seems desirable to simplify the problem and determine first whether certain morphological effects are related to yield and if so with what degree of regularity. It appears logical to assume that yield is the function of (a) the number of plants per acre, (b) the number of heads per plant, (c) the number of kernels per head, and (d) the size of the kernel. An increase in any one or more of these without a corresponding decrease in one or more of them will result in an increased yield.

The time at which an ecological condition prevails or the nature of that condition may determine which of the four factors for yield will be affected, e.g., drought very early in the spring may influence tillering and reduce the number of heads, but drought shortly before harvest can influence only the size of the kernel. Bunt exerts its influence on yield primarily through the effect on number of heads, whereas stem rust affects yield chiefly through its influence on the size of the kernel.

With respect to varieties it has been observed that, in general, ecological conditions which favor high yield of one adapted variety will also favor high yields in other adapted varieties. It is evident that varieties differ as to their normal tillering, size of head, and size of kernel as well as other characters but many of the ecological conditions which tend to modify such characters in one variety will have a similar effect in other varieties. With respect to certain causes, however, varietal response may be greatly different. A familiar example is stem rust which may cause a low yield or the failure of a susceptible variety but have little effect on the yield of a highly resistant variety.

The general ecological conditions affecting wheat may be designated as those of season and those of location. Limited study of these indicates that seasonal conditions ordinarily establish a general pattern of plant growth, development, and yield. In any given season, however, wide variations in yield and plant characters often occur as a result of differences in the ecological conditions of different locations.

The relations between plant characters and yield are more apparent when the ecological conditions differ widely enough to induce large or moderately large differences in yield for then the differences in corresponding plant characters also tend to be large. Often in replicated varietal experiments the ecological conditions in the various replicates are so nearly alike as to cause little, if any, more fluctuation in yield and in most of the associated plant characters than is accounted for by experimental error, thus the "within variety" relationships of plant characters with yield are difficult to measure.

Data which are obtained from a wider range of ecological conditions within each year would appear desirable, at least for a preliminary study of the relation between plant characters and yield. An experiment which provides such data is being made at the Kansas Agricultural Experiment Station where since 1932 wheat has been seeded at intervals throughout the fall, the number of dates of planting being five in 1936, six in 1932, eight in 1935, and seven in each of the other three years. Thus in each year wheat has been grown in from five to eight more or less distinct ecological conditions. The varieties used in these experiments responded similarly to ecological conditions and therefore the average data for the four varieties are presented.

The data taken include yield, number of heads per acre, and bushel weight of wheat grown in each of the ecological conditions from 1932 to 1937 and weight per 1,000 kernels from 1934 to 1937. The relationships among the several characters and yield are shown graphically in Fig. 1. The different environments are represented at intervals from left to right across the graph in order of decreasing yield. Thus what presumably was the best condition is indicated at the left and the poorest at the right. The yield (Y) for each environment is indicated at points connected by the solid line, the number of heads (H) by the long dash, and the bushel weight (T) or kernel weight (K) by the short dash. The number of heads are reported as 1/10,000 the estimated number per acre, bushel weight as pounds per measured bushel, kernel weight as grams per 1,000 kernels, and yield as bushels per acre.

In 1932 there was a general relation between the number of heads and yield, and except in one case, a decrease in yield was associated with a decrease in test weight.

The best three ecological conditions in 1933 when the yields were about 45 bushels indicate an inverse relation for both number of heads and test weight when compared with yield. With lower yields there was a corresponding decrease in both of the other characters.

A positive correlation between kernel weight and test weight often has been observed and is believed to be general. The graph for 1934 includes weight per 1,000 kernels instead of test weight as for the previous years. A nearly constant relation was observed between the number of heads per acre and weight of the kernels on one hand and yield on the other, in fact the discrepencies probably do not exceed the experimental error.

In 1935 the close relation was found between kernel weight and yield, in fact every change in yield was associated with a similar change in weight of kernels. The lack of relation of number of heads

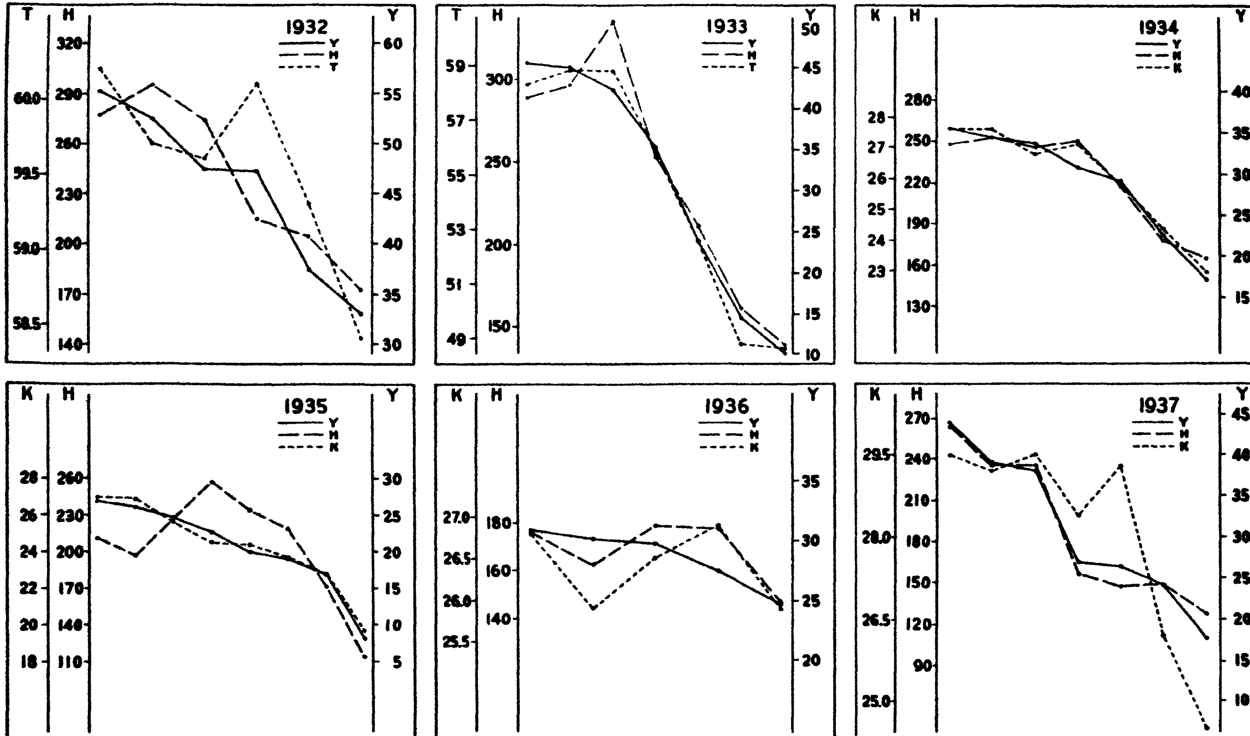

FIG. 1.—Relation between yield (Y), number of heads per area (H), and test weight (T) or kernel weight (K) of wheat grown in different ecological conditions at Manhattan, Kansas, 1932 to 1937. The best ecological condition indicated by the highest yield, is shown at the left and the poorest at the right of each graph.

compared with the previous years may have been due to the prolonged April and early May drought of that year. Such a disturbance at that time in the season may also account for the very close relationship between size of kernel and yield since the yield apparently was determined largely by the capacity of the plant to manufacture materials and translocate them into the existing kernels during the favorable weather which occurred late in the season.

The results for five ecological conditions studied in 1936 indicate that some other factor or factors than number of heads and size of kernel were important in influencing the yield of wheat. This suggests the need for complete data regarding the crop and conditions affecting it and also the importance of season variation which may bring different factors into important relation with yield.

In 1937 the relationship between number of heads and yield was much better than between size of kernel and yield. The importance of number of heads in relation to yield also was observed in that season within varieties in triplicate variety test plats.

It is fully realized that this limited interpretation of data is only preliminary and that detailed statistical treatment should be given the agronomic results. Even though it is shown, after further study, that a few simple measurements are related to yield, the question will not yet be answered but will only be opened for really intensive study. For it is perhaps more important to the development of science to know why the number of heads vary and what are the causes for differences in weight of kernels. The answer in general can now be stated, but can the cause in relation to yield or in terms of probable yield be interpreted? For example, What is the influence on yield of drought at a certain time in the life of the plant? What is the probable effect on yield of a moderate infection of leaf rust at a certain stage of the crop? Answers to these and many other questions await solution. It is not within the realm of this paper to go into that phase of the question, but rather to point out that it may be possible to make certain observations and measurements of the plant which have a probable relation to yield.

The highly variable climate of the hard winter wheat region adds to the difficulty of determining relations that are even moderately consistent from year to year. If the critical ecological condition strikes late in the life of the plant the effect must be different than if it occurs early in the season. The adverse condition at either time probably will reduce the yield, but if it comes near the time of maturity only the size of the kernel will be influenced whereas if the unfavorable condition occurs early in the spring the number of heads, the size of the head and perhaps also the size of the kernel may be affected. If the adverse condition prevails at seeding time the number of plants (stand) in addition to the other characters may be influenced.

Even with such highly variable conditions it appears that the expression of ecological factors upon the growth or character of the crop can be interpreted with some degree of reliability to indicate a probable yield.

A knowledge of how the plant is influenced by environmental conditions and of the relation of those influences to yield also will indicate

what genetic features need to be changed in order to improve the adaptation and yield of a variety. Furthermore, this information will point out how ecological conditions for the crop can be improved by tillage practices, fertilizer treatments, time and rate of seeding, etc.

In conclusion, may the suggestion be made that it appears important and decidedly worthwhile to learn whether and to what extent physical conditions of the environment affect the physiology of the plant so as to modify its morphology in a way that is related to yield.

RENOVATION AND ITS EFFECT ON THE POPULATIONS OF WEEDS IN PASTURES[1]

R. F. FUELLEMAN AND L. F. GRABER[2]

IN southwestern and western Wisconsin, over 45% of the land area is in permanent pasture. The dominant species is bluegrass (*Poa pratensis*). The topography is such that extensive utilization of the land for grazing has been required as a means of erosion control. Much credit is due the farmers of this region for their efforts in maintaining this far-sighted policy of soil conservation. But, as is so often true of grasslands, many of the permanent pastures of this region have suffered severe declines in productivity and quality within the last 10 years.

Numerous interacting factors are involved. It seems that the very attributes of such a biotic complex are either cumulatively destructive or cumulatively constructive. The middle ground does not seem to prevail for long. A waning fertility with 50 or more years of grazing without restoration of plant nutrients does not manifest its influence on the vegetation spontaneously, but it does ultimately. Add to it, the stress of several seasons of excessive heat and drought, the inevitable tendency for early and continuous close grazing with declines in the carrying capacity, and then, the cumulative nature of things destructive will manifest itself. It did in southwestern and western Wisconsin as it has done elsewhere. The interacting conditions like these thinned the bluegrass sods and widely extended the egg-laying areas of the June beetle (*Phyllophaga* sp.). Enormous populations developed in 1929, 1932, and 1935, and the wholesale injury of the grass covering by the larvae (white grubs) was very severe. Then followed weeds—ragweeds, horseweeds, and many others which could easily compete with grass, beleagured by heat, drought, overgrazing, and grubs.

RENOVATION

A plan of pasture improvement with attributes that were cumulatively constructive over a period of years was needed to meet such a drastic situation. Such a plan was attained, to a marked degree, in the practices of pasture renovation. The method[3] of establishing deep-rooted dry-weather legumes, alfalfa (*Medicago sativa*), sweet clover (*Melilotus alba* or *officinalis*), and red clover (*Trifolium pratense*), in permanent but thin grass sods without plowing, have reached the status of substantiated farm practice in many regions.

Unlike plowing, the scarification of grass sods with a disk or spring tooth harrow maintains, to a high degree, the binding power of the grass roots; and with the broken sods remaining on the surface, it is

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[3]GRABER, L. F. Renovating bluegrass pastures. Circ. 277, Col. of Agr., Univ. Wis. 1936.

possible to establish productive and drought-enduring legumes on steep slopes with a minimum danger of erosion. Moreover, renovation has effectively controlled the injury of white grubs. It has induced much-needed liming and fertilization of pastures with phosphates and potash. It has reduced drought hazards and has enhanced fertility by virtue of the associated growth of leguminous plants with grasses. And with all these cumulative merits, it has greatly reduced the prevalence of undesirable species, particularly, unpalatable weeds. It is the purpose of this paper to show how effectively weed control has been accomplished after the dry-weather legumes were established in permanent pastures.

PROCEDURE

In 1934 and 1935 portions of from 2 to several acres of 30 widely distributed permanent pastures were renovated. As reported by Fuelleman and Graber,[4] such renovations almost completely eliminated subsequent injury to the grass by white grubs, reducing their populations from 91 to 98% when compared with the populations which prevailed in the adjacent non-renovated portions of these widely distributed pastures.

During the summer of 1937 weed counts were made on 27 of these renovated areas and on 27 adjacent areas not renovated Weed counts were also made in 3 additional pastures where portions had been renovated, thus providing 30 pastures for the weed study.

In this weed survey, a quadrat having an enclosed area of 1/20,000 acre was used. The pasture under scrutiny was examined and the vegetational trends noted. It was found in most cases a diagonal course across the area gave a better picture of the weed population. The quadrat was thrown at random, the distance between throws being equalized by pacing and avoiding, in so far as possible, obstacles such as gulleys, old fence rows, etc. The species and number of weeds were noted and recorded upon suitable charts. Each species was recorded by number (Table 1). A total of 10 samples was taken from each of the renovated and non-renovated portions of the pastures. In all cases the portions of the non-renovated pastures used for making sample counts were approximately of the same size as the portion renovated.

CHARACTER OF WEED GROWTH

The plants which were regarded as weeds are given in Table 3. Most of them were annuals. Ragweeds (*Ambrosia artemisiifolia*) and horseweeds (*Erigeron canadensis*) were most generally prevalent. In the non-renovated portion, where weeds were most abundant, ragweeds represented the highest percentage of the total weed population in 15 pastures, horseweeds in 13 pastures, mock pennyroyal (*Hedeoma hispida*) in 1 pasture, and catsfoot (*Antennaria compestris*) in 1 pasture. Other weeds which constituted from 20% to 36% of the total weed population s and could be regarded as prominent sub-dominants in the non-renovated bluegrass were mock pennyroyal in 5 pastures, red sorrel (*Rumex acetesolla*) in 1 pasture, yarrow (*Achillea millefolium*) in 1 pasture, sandwort (*Sabulina sp.*) in 1

[4]FUELLEMAN, R. F., and GRABER, L. F. Pasture renovation in relation to populations of white grubs. Jour. Amer. Soc. Agron., 29: 186–196. 1937.

TABLE 1.—*Weed species found in unrenovated and renovated portions of 30 pastures.*

Weed No.	Scientific name	Common name
1	*Lychnis alba*	White campion
2	*Rumex crispus*	Curled dock
3	*Erigeron canadensis*	Horseweed
4	*Ranunculus acris*	Tall buttercup
5	*Viola pedatifolia*	Yellow violet
6	*Achillea millefolium*	Yarrow
7	*Ambrosia artemisiifolia*	Ragweed
8	*Taraxicum officinale*	Dandelion
9	*Potentilla monspeliensis*	Cinquefoil
10	*Erigeron ramosus*	Daisy fleabane
11	*Silene noctiflora*	Sticky catchfly
12	*Thlaspi arvense*	Pennycress
13	*Veronica peregrina*	Speedwell
14	*Lepidium apetalum*	Small peppergrass
15	*Lepidium campestre*	Tall peppergrass
16	*Rumex acetosella*	Red sorrel
17	*Chenipodium alba*	Lambs quarter
18	*Amaranthus retroflexus*	Pigweed
19	*Polygonum aviculare*	Knotweed
20	*Chrysanthemum Leucanthium*	Oxeye daisy
21	*Hedeoma hispida*	Mock pennyroyal
22	*Silene anthirrhina*	Large chickweed
23	*Specularia perfoliata*	Venus looking glass
24	*Bursa pastoris*	Shepard's purse
25	*Polygonum convulvulus*	Black bindweed
26	*Oxalis violacea*	Small sorrel
27	*Asclepias syriaca*	Common milkweed
28	*Verbena hastata*	Smooth vervain
29	*Polygonum hydropiper*	Smartweed
30	*Polygonum Persicaria*	Lady's thumb
31	*Verbena stricta*	Hoary vervain
32	*Chamaesyce maculata*	Spotted or creeping spurge
33	*Agropyron repens*	Quack grass
34	*Panicum capillare*	Witch grass
35	*Linaria vulgaris*	Toad flax
36	*Verbascum thapsus*	Mullen
37	*Antennaria campestris*	Catsfoot
38	*Sabulina* sp.	Sandwort
39	*Setaria* spp.	Foxtails, green and yellow
40	*Cirscium arvense*	Canada thistle
41	*Plantago majus*	Plantain
42	*Erigeron annus*	Field daisy
43	*Euphorbia peplus*	Flowering spurge
44	*Physalis lobata*	Ground cherry
45	*Cerastium vulgatum*	Mouse-eared chickweed
46	*Nepata cataria*	Catnip
47	*Cirscium lanceolatum*	Bull thistle

pasture, lady's thumb (*Polygonum persicaria*) in 1 pasture, catsfoot (*Antennaria compestria*) in 2 pastures, and spotted spurge (*Chamasyce maculata*) in 1 pasture.

WEEDS AS INDICATORS OF PASTURE IMPROVEMENT

It is well recognized that the prevalence of undesirable species in a pasture is indicative of the productivity of the desirable species.

An abundance of annual and biennial weeds in grasslands is generally a result of a reduction in the competitive efficiency of desirable grasses and legumes. This may result from improper grazing, from deficiences in fertility, from excessive heat and drought, from grub injury, or from other broad limitations of this nature. Given a favorable environment and proper grazing management, there are few annual and biennial weeds which can long compete with desirable grasses and particularly is this true of pastures where bluegrass is dominant in southwestern and western Wisconsin. Even perennials do not make great progress in their spread if the density of the sod is maintained and the regenerative activity of desirable grasses is kept at a high and productive level. We may, therefore, regard the weed population data obtained in this study as a rough and partial measure of the degree of pasture improvement by renovation methods.

WEED POPULATIONS REDUCED BY RENOVATION

The season of 1937 was of a character to encourage an abundance of summer weeds in permanent pastures of western and southwestern Wisconsin. Ample moisture prevailed in the forepart of the season, but it was followed with severe drought and heat in July and August and early September, thus favoring the growth of many resistant species but particularly ragweeds and horseweeds.

The effect of renovation under such conditions on the total weed populations of 30 widely distributed pastures is shown in Fig. 1 and Table 2. Elimination was not complete, but the reduction as a result of renovation are very marked. In the portions of 27 pastures renovated in 1934 and 1935, weeds were 85.7% less in numbers than on the adjacent areas not renovated. When it is considered that weeds in the non-renovated areas of these 27 pastures were prevalent at the average of nearly 1 million per acre (varying from 412,000 to 1,876,000), such reductions are very substantial. Renovation of a portion of one pasture in 1936 reduced the population of weeds in 1937 by 73.0% and with another renovation in 1935 the reduction in weed populations in 1937 was 91.0%.

TABLE 2.—*Number of grubs per acre in 1936 and the number of weeds per acre in 1937 on adjacent non-renovated and renovated portions of 30 widely distributed permanent bluegrass pastures in western and southwestern Wisconsin.*

No. of pastures on which determinations were made	Year portions of pastures were renovated	Average no. of grubs per acre in 1936		Average no. of weeds per acre in 1937		
		Portion not renovated	Portion renovated	Portion not renovated	Portion renovated	% reduction
15	1934	133,580	1,636	937,067	132,667	85.8
12	1935	165,552	15,241	1,019,833	146,167	85.7
1	1929	117,612	23,950	2,554,000	162,000	93.6
1	1935	—	—	1,004,000	90,000	91.0
1	1936	—	—	808,000	218,000	73.0

Of particular interest is the renovation of 4 acres of a large pasture in 1929. This area (Table 2) had passed through three heavy flights of egg-laying June beetles (*Phyllophaga sp.*) without sufficient egg-depositions to exhibit a noticeable degree of white grub injury. Its condition in 1937 is well illustrated by a weed population of 162,000 per acre compared with 2,554,000 per acre in the adjacent pasture area of 4 acres which had never been renovated. It so happens that this is the oldest outlying renovation area in Wisconsin. The soil was

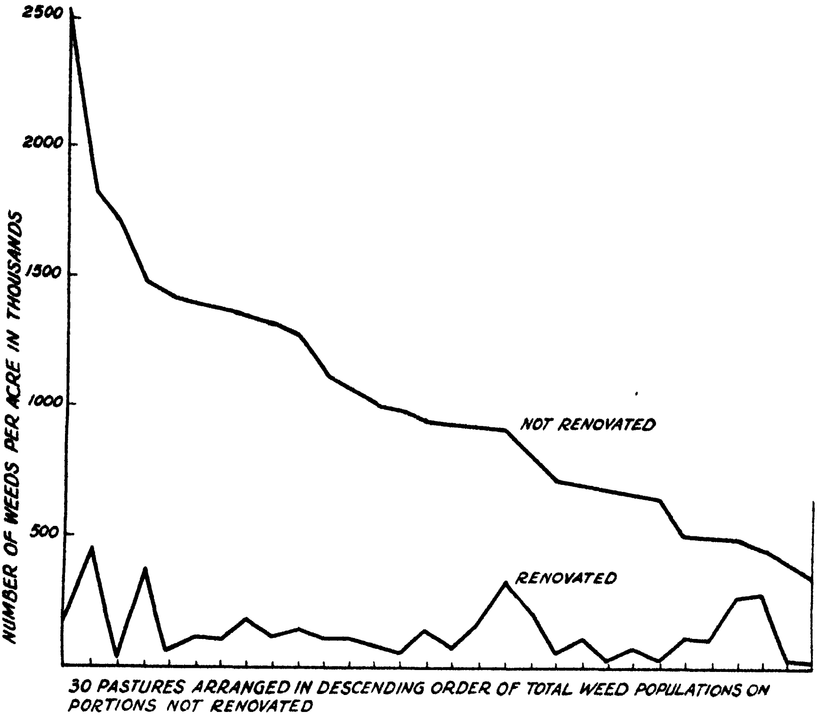

FIG. 1.—A comparison of the total number of weeds per acre in 1937 on the renovated and non-renovated portions of each of 30 widely distributed bluegrass pastures in western and southwestern Wisconsin. The pastures are arranged in the descending order of the number of weeds per acre on the non-renovated portions.

very low in fertility and ample lime and superphosphate were applied in 1928 to the 4-acre area which was to be renovated with biennial white blossomed sweet clover. An excellent stand was obtained in 1929 and by means of grazing management this leguminous plant has regularly re-established itself by self-seeding for the past 7 years, including 1937. It is now and has been a clear-cut demonstration of the lasting and residual improvement which prevails with the practices involved in successful renovation.

The populations of horseweeds and ragweeds were very effectively controlled by renovation. In 30 pastures where ragweeds prevailed at the average rate of 423,200 per acre in the non-renovated portions,

renovation reduced them to 60,400, or 85.7%. In 30 pastures where horseweeds prevailed at the average rate of 336,267 per acre in the non-renovated portions, renovation reduced them to 26,600 per acre, or 92.1%.

PREVALENCE OF RAGWEEDS AND HORSEWEEDS NEGATIVELY CORRELATED

In the non-renovated areas of the 30 pastures an abundance of ragweeds (*Ambrosia artemisiifolia*) was associated with a reduced number or the absence of horseweeds (*Erigeron canadensis*), as shown in Table 3 and Fig. 2. The negative correlation coefficient between the percentages of the total weed populations consisting of ragweeds and of horseweeds is –.78. This shows that, in general, a high percentage of one of these two weeds in the non-renovated pastures was correlated with a low percentage of the other. In the non-renovated areas where both ragweeds and horseweeds prevailed, the two species did not grow very generally in association with each other, but

TABLE 3.—*Total number of ragweeds and of horseweeds per acre and the percentages of the total number of weeds per acre consisting of ragweeds and of horseweeds in each of the unrenovated portions of 30 pastures in western and southwestern Wisconsin.*

Pasture No.	Total no. of weeds per acre (000) omitted	Ragweeds		Horseweeds	
		No. (000) omitted	%	No. (000) omitted	%
25	358	354	98.9	0	0.0
34	2,554	2,260	88.5	4	0.2
8	512	438	85.5	10	1.9
3	506	408	80.6	0	0.0
21	1,264	958	75.8	176	13.9
14	932	636	68.2	102	10.9
10	1,478	946	64.0	228	15.4
23	652	398	61.0	154	23.6
20	928	512	55.2	12	1.3
6	716	386	53.9	26	3.6
31	808	398	49.3	58	7.2
15	1,118	486	43.5	360	32.2
7	994	402	40.4	274	27.6
12	702	280	39.9	162	23.1
29	1,394	554	39.7	440	31.6
9	1,332	514	38.6	654	49.1
2	1,062	394	37.1	516	48.6
5	1,316	460	34.9	498	37.8
28	1,408	404	28.7	652	46.3
27	1,750	460	26.3	898	51.3
4	930	210	22.6	74	7.9
1	674	148	21.9	288	42.7
16	1,876	372	19.8	944	50.3
24	472	94	19.9	212	44.9
19	510	76	14.9	98	19.2
13	412	56	13.6	100	24.3
26	692	40	5.8	320	46.2
22	934	44	4.7	598	64.0
11	1,372	8	0.6	1,362	99.3
33	1,004	0	0.0	872	86.9

rather the horseweeds tended to prevail in patches separate from the patches of ragweeds. Unfortunately, data were not collected to measure the degree of such dissociation in the growth of the two species within any given pasture nor has the nature of the apparent antagonism between them been ascertained.

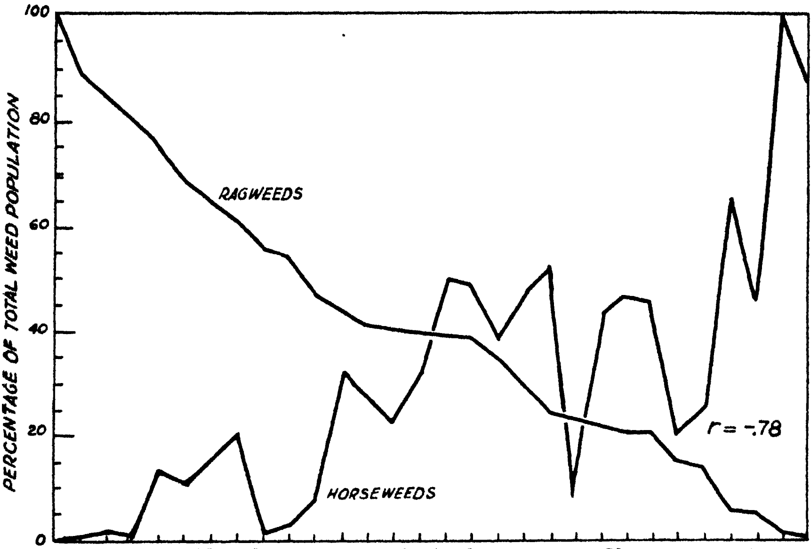

FIG. 2.—A comparison of the percentages of the total weed populations, consisting of ragweeds and horseweeds, on the non-renovated portions of 30 widely distributed bluegrass pastures of western and southwestern Wisconsin in 1937. The pastures are arranged in the descending order of the percentages of ragweeds to show the relationships with the percentages of horseweeds.

DISCUSSION

Since the data covers a period of one summer only, it is not feasible in this time-limited study to attempt to associate the weed growth in 1937 with specific factors. In outlying trials of this character the collection of data on causal factors was handicapped by a lack of adequate controls and supervision. Of course, it was true that the prevalence of white grubs in 1936 had, in a broad way, a very considerable influence on weed growth in 1937, but because of other factors involved the exact effect of previous grub injury of the grass sods on the subsequent weed growth is not ascertained. Likewise, the influence on weed growth of such practices as liming, fertilization, cultivation, and deferred grazing, which were necessary for the success of the renovations, is not determined nor is the influence of the legumes themselves. While the 30 non-renovated areas were grazed more or less uniformly, only 20 of the renovated areas were used solely for grazing, 6 were cut for hay and 4 were utilized for hay and pasturage. Such diversity of treatment of the renovated portions

did not seem to influence materially their total weed populations, but the means of actually measuring the effects it may have occasioned were not available. What was accomplished in these trials has been the determination of the gross effect of all such variable interacting factors on weed populations rather than a differentiation of the influence of any single factor.

SUMMARY

Renovation of permanent grasslands in Wisconsin is a method of pasture improvement involving the establishment of such dry-weather legumes as alfalfa (*Medicago sativa*), sweet clover (*Melilotus alba* and *officinalis*), and red clover (*Trifolium pratense*) in thinned pasture sods without plowing.

Portions of 30 widely distributed bluegrass pastures in western and southwestern Wisconsin were renovated in 1929, 1934, 1935, and 1936. In 1937, the populations of species regarded as weeds were determined in the renovated areas and in adjacent areas of equal size not renovated.

The 27 renovations of 1934 and 1935 reduced the total weed populations 85.7% in 1937, and likewise a reduction of 91.0% and 73.0% resulted from one renovation in 1935 and one in 1936, respectively. Nine years after the renovation of a 4-acre area of another pasture the total weed population was 93.6% less than that of the adjacent area of 4 acres not renovated.

Ragweeds (*Ambrosia artemisiifolia*) and horseweeds (*Erigeron canadensis*) were the most generally prevalent species. In 30 pastures, renovation reduced ragweeds 85.7% and similarly horseweeds were reduced 92.1%.

Where high percentages of the total weed populations of the non-renovated portions of the 30 pastures consisted of ragweeds, the percentages of horseweeds were low and the negative correlation coefficient between such percentages was -.78.

TREND STUDIES IN RELATION TO THE ANALYSIS OF YIELD DATA FROM ROTATION EXPERIMENTS[1]

K. H. W. KLAGES[2]

THE usual method of analysis of yield data from rotation experiments is based strictly on a presentation of the average yields obtained. While average yields are indispensable to any presentation of results from rotation and other field plat experiments in general and offer the best direct basis of comparison of various plat treatments, they may nevertheless be supplemented to advantage by additional criteria, such as evaluation of trend relationships and expressions of seasonal variability. The writer found in presenting the results of rotation experiments to groups of producers that as much, if not more, interest was shown by farmers in the trend relationships as in the average yields obtained from the various sequences of cropping. A graphical presentation of yield trends met with exceptionally good reception. The trend relationships were in all cases discussed in connection with the average yields obtained.

The above referred to producer response to trend relationships of crop rotation data provided the main impetus for presenting this type of analysis at this time.

MATERIALS AND METHODS

The yield data of 10 rotations conducted on the University Farm at Moscow, Idaho, were available for analysis. These rotation experiments were started in 1915 and have been carried up to date, making the yield data of a 23-year period available. Except in the case of the potato plats, the same varieties were used during the course of the experiment. Obviously, the substitution of varieties with differing yielding capacities may materially influence trend relationships. The varieties used were Red Russian winter wheat, Swedish Select oats, Alaska peas, Rustlers White Dent corn, and Early Ohio, Bliss Triumph, and Katahdin potatoes. These rotations, with their crops and practices in their order of sequence are presented in Table 1. It is not the object of this paper to discuss the relative merits of these various systems of cropping to Idaho conditions. The yield, trend, and variability data pertaining to them are given only for purposes of presenting a method of analysis.

LINEAR AND CURVILINEAR TRENDS

Yield data may be fitted to various types of curves depending on the particular types of trends shown and closeness of fit. For purposes of providing supplementary information to the interpretation of mean yields, straight line trends have several decided advantages over curvilinear trends.

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[1]Contribution from the Department of Agronomy, University of Idaho, Moscow, Idaho. Published with the approval of the Director as Research Paper No. 166 of the Idaho Agricultural Experiment Station. Received for publication March 31, 1938.

[2]Professor of Agronomy.

Straight line trends call for the calculation of but one variable to designate a uniform positive or negative slope of the trend line, while curvilinear trends demand the rather laborious calculation of two or more such variables. While straight line trends are not applicable to all compilations of yield data, they indicate the general or average trend of a yield test extending over a period of years in a direct and readily understandable manner. A producer contemplating a modification in his system of cropping has a right to inquire as to the trends that his yields may be expected to take by adapting a rotation recommended to him. Such a question is more readily and directly answered by information relating to trends of yields shown by experimental plats devoted to designated systems of cropping than by a mere recitation of averages. In such instances the average or straight line trend is especially useable. It is recognized, as will be brought out later, that the straight line analysis may not give all the available information regarding a trend relationship. It does, however, have the outstanding advantage of directness by providing a single figure characterizing the slope of the trend line which is easily comprehended by the layman with little knowledge and not infrequently less appreciation of higher mathematics.

THE STRAIGHT LINE TREND

The straight line trends presented were calculated by the method of least squares. The formula of the required line is $y=ax+b$.

The slope of the line "a" and the y-intercept "b" are determined from the observed pairs of values of x and y. The yield data are plotted by designating the successive years of the experiment by x values and placing them on the x axis. Since the graph starts at the point of origin the value of x for the initial year of the experiment is 0. The respective yields, the y values, for the successive years of the experiment are plotted on the y axis. When "a" and "b" are known, the value of y can be calculated for any selected value of x. With a calculating machine available the required calculations can be carried out with speed and precision.

The equation for the required line of least squares for the wheat yields in rotation 1 is found to be $y=1.26x+38.97$. Fig. 1 shows the seasonal yields of wheat in rotation 1 together with the straight line and parabola trends. It will be observed that the linear trend line shows, since the value of "a" is positive, a rise of 1.26 bushels per year. The y axis is intercepted at 38.97 bushels, that is at the calculated value of "b". The extremities of the straight line trend extend from 38.97 to 66.69 bushels for the values of x at 0 and 22, respectively.

In rotation 4 a positive trend is in evidence for the wheat, while the oats yields show a definite negative trend. The value of "a" for the equation of the line of least squares for the wheat yields is 0.63 with the extremities extending upward from 45.67 to 59.53 bushels. Since the equation of the linear trend line for the oats yields is $y=-0.52x+48.00$ the extremities of the line extend downward from 48.00 to 36.56 bushels for the values of x at 0 and 22, respectively, thus showing an average yearly decrease of 0.52 bushel per acre.

The trend relationships of the oats yields of rotation 4 are shown graphically in Fig. 2.

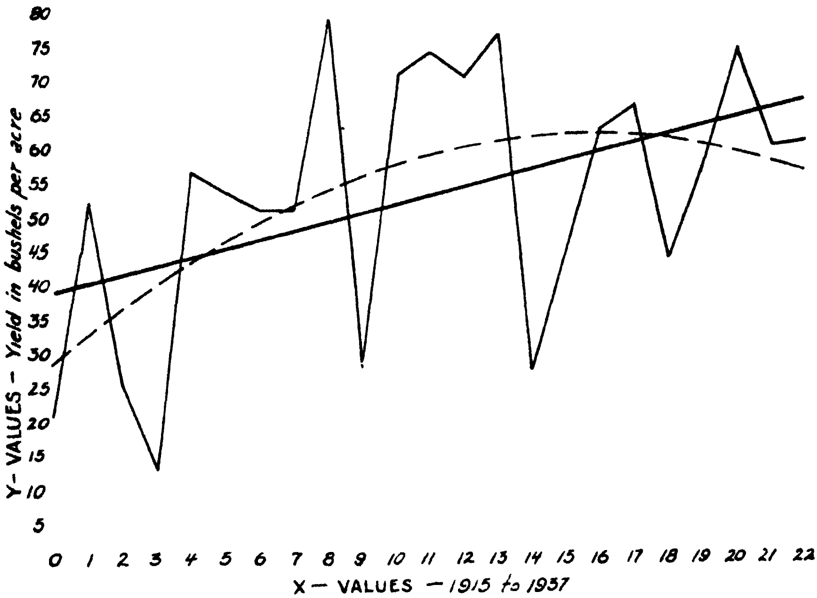

FIG. 1.—Straight line and parabola trends of the seasonal yields of wheat in rotation 1 from 1915 to 1937, inclusive.

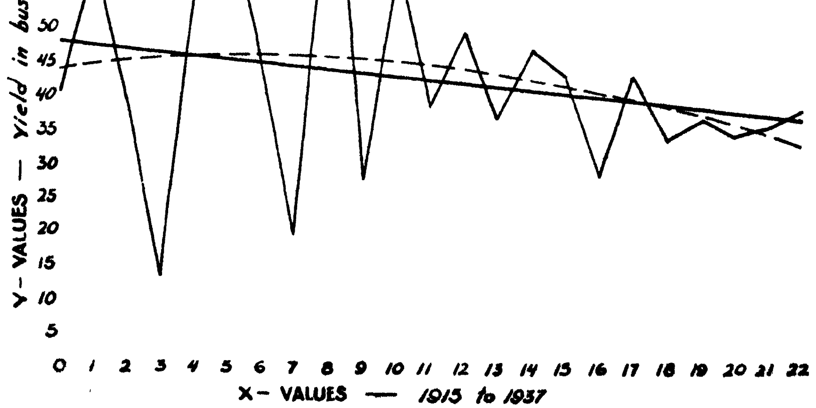

FIG. 2.—Straight line and parabola trends of the seasonal yields of oats in rotation 4 from 1915 to 1936, inclusive.

The above examples suffice to show the practical significance of straight line trends. Table 1 gives the average yields, yield trends, extremities of the trend lines for the course covered by the experiments, and the coefficients of variability of the seasonal yields for each of the crops of the 10 rotation systems previously referred to.

TABLE 1.—*Average yields, straight line trends, and variability in the seasonal yields of crops in rotations on the University Farm, Moscow, Idaho, for a 23-year period, 1915 to 1937, inclusive.*

Rotation No.	Crops and sequence	Average yield, bu.	Yield trend	Extremities of trend lines	Coef. of variability of seasonal yields
1	Wheat	52.9	+1.26	38.97–66.69	36.00±4.05
	Oats	63.5	+1.26	49.60–77.32	35.79±4.03
	Peas plus manure	20.0	−0.51	25.15–14.95	43.31±5.34
2	Wheat	43.0	+0.47	37.82–48.16	31.47±3.48
	Oats	47.1	+0.20	44.96–49.36	33.43±3.70
	Peas	20.3	−0.42	24.50–16.10	40.72±4.93
3	Wheat	56.4	+0.96	45.86–66.98	30.99±3.40
	Oats	56.1	+0.46	51.04–61.16	40.50±4.68
	Fallow plus manure	—	—	— —	— —
4	Wheat	52.5	+0.63	45.67–59.53	25.28±2.69
	Oats	42.3	−0.52	48.00–36.56	35.54±4.00
	Fallow	—	—	— —	— —
5	Wheat	50.0	+1.18	37.03–62.99	32.33±3.57
	Oats	59.7	+0.62	52.84–66.48	33.81±3.77
	Corn plus manure	7.82*	−0.11	8.96– 6.65	35.70±4.11
6	Wheat plus 200 lbs. $NaNO_3$	47.4	+0.10	46.27–48.47	25.08±2.67
	Oats	48.3	−0.67	55.65–40.91	40.46±4.68
	Potatoes, 1916–1922	120.7			
	Corn, 1923–1937	5.51*			
7	Wheat	34.3	+0.24	31.75–37.03	29.21±3.17
	Oats	42.4	−0.24	45.06–39.78	34.74±3.88
	Corn	5.61*	−0.12	6.87– 4.35	34.87±3.98
8	Wheat	49.2	+0.17	47.30–51.04	25.05±2.67
	Oats	47.1	−0.51	52.64–41.42	36.14±4.07
	Potatoes	84.5	−3.36	119.71–49.15	49.12±6.16
11	Continuous wheat plus manure:				
	Replication A	29.5	+0.15	27.84–31.14	44.61±5.29
	Replication B	35.9	−0.06	36.60–35.28	41.85±4.88
	Replication C	34.7	−0.002	34.71–34.67	35.50±4.00
	Average	33.4	+0.03		40.65
12	Continuous wheat:				
	Replication A	20.1	−0.15	21.76–18.46	44.60±5.29
	Replication B	24.1	−0.09	25.09–23.11	36.83±4.18
	Replication C	23.7	−0.28	26.75–20.59	37.40±4.25
	Average	22.6	−0.17		39.61

*Tons.

Since the respective equations for the trend lines can be readily constructed from the information given it is not necessary to take space to give them in Table 1.

The trend data here presented cannot be used for purposes of predicting the future yields of the plats on which they are based. It cannot be expected that the high upward, and in some instances downward, trends will continue at their past rates. Sooner or later a state of equilibrium will be reached in the yields of these crops. There is some evidence that this point has already been reached in the case of some of the rotations. More will be said about this point in the discussion of parabola trends. The exact position of this yield equilibrium will be determined by the climatic conditions under which the crops are grown and by the soil changes induced by the different systems of cropping. Progressive soil changes in turn can be expected to modify the response of the plants grown to the particular climatic features of their environment.

YIELD AND TREND RELATIONSHIPS

It will be observed from Table 1 that the high-yielding plats of winter wheat and oats in the various rotation systems generally also show relatively high upward trends, while the low-yielding plats show either low, or in some instances, definite negative yield trends. The higher yields and also the higher upward yield trends in the rotations to which manure is applied as compared with the lower and not infrequent negative trends of the rotations not receiving manure are especially noteworthy. Rotation 1 shows a wheat yield of 52.9 bushels and a positive trend of 1.26 bushels, while the wheat yields of the corresponding rotation 2, without applications of manure, shows a yield of only 43.0 with a trend of 0.47 bushel.

The differences in the oats yields and trends in rotations 1 and 2 are even more pronounced than for the wheat. The differences in the yields of the wheat and oats in rotations 3 and 4 become especially significant when they are considered in the light of their trend relationships. The differences in the yields and trends of the wheat following the fallow are not as outstanding as those of the second crop following the fallow, that is the oats. The beneficial effects of the fallow are apparently taken up completely, or nearly so, by the wheat without any significant carry-over effect to the oats crops.

With the applications of manure the oats in rotation 3 yields 56.1 bushels and shows a positive trend of 0.46 bushel as against a yield of only 42.3 bushels and a definite negative trend of −0.52 bushel in rotation 4, in which no manure is used. The average yields of the continuous wheat plats in rotation 11 with the application of manure show a slight positive trend while those in the corresponding rotation 12, continuous wheat without the application of manure, show a definite negative trend. The manure in all the rotation plats, designated as plus manure in Table 1, is applied at the rate of 15 tons per acre every third year.

A correlation between the average yields of the 14 wheat plats included in the various rotations and their respective trend evalua-

tions showed a value of "r" $=0.8025 \pm .0666$. A corresponding calculation of "r" for the average yields and trend evaluations in the case of the eight oats plats gave a correlation of $0.8779 \pm .0584$.

STRAIGHT LINE YIELD TRENDS IN RELATION TO RAINFALL TRENDS

The yield trends exhibited by crops in a series of rotation experiments may be due either to induced soil changes or to variations in climatic conditions, especially moisture relationships, over the period of the test. The influence of moisture relationships will be especially disturbing in the event of progressive changes in a given direction. That such progressive changes did not play a significant part in the trends of yields shown by the crops in the rotation systems under discussion is brought out in Table 2 giving the annual and seasonal trends in precipitation at Moscow, Idaho, for the duration of the rotation experiments. The most significant positive trend is exhibited for the winter months of December to March, inclusive. The annual precipitation shows but a slight positive trend, while the August to November, as well as the April to July, trends are slightly negative.

TABLE 2.—*Annual and seasonal trends in precipitation at Moscow, Idaho, for the period 1915 to 1937, inclusive, calculated by the method of least squares.*

Periods of precipitation	Rainfall trends	Equation of line of least squares	Extremities of trend lines
Annual	+0.09	$y = .09x + 20.23$	20.23–22.21
Aug., Sept., Oct., and Nov.	−0.02	$y = -.02x + 6.14$	6.14– 5.72
Dec., Jan., Feb., and March	+0.14	$y = .14x + 8.94$	8.94–12.02
Apr., May, June, and July	−0.04	$y = -.04x + 5.20$	5.20– 4.32

PARABOLA TRENDS OF YIELD DATA

The graphic presentation of the seasonal yields suggests the possibility that a curved line may fit the obtained yield data better than a straight line. That this is the case in most instances is brought out in Table 3 giving summations of the total deviations, plus and minus, of the actual and the calculated values of y. Figs. 1 and 2 give the straight line and the parabola trends of the seasonal yields of the wheat in rotation 1 and the oats in rotation 4. A second order parabola is used for these calculations, the equation for which is $y = ax^2 + bx + c$. This equation demands the solving of three unknowns, a, b, and c. When these values are determined, y may be calculated for any selected value of x.

It will be observed from Table 3 that the closeness of fit of the yield data to the trend lines is not materially better for the parabola than for the straight line trends. As a matter of fact, in the case of the oats in rotation 1, the linear trend gives a slightly better fit than the curvilinear one.

The fact that the parabola trends fit the data as well or slightly better than straight line trends brings out one fact, namely, that the upward trends, and in some instances the negative ones, were not at the same rate for the entire period covered by the experiment. In the

case of those rotations showing positive trends the upward swing of the yields was greater during the initial than for subsequent periods. This same fact can also be demonstrated by calculating the straight line trends for the first 11 and the subsequent 12 years over which the experiment extended. In other words, the yields on some of these rotations are approaching an equilibrium.

TABLE 3.—*Comparative total deviations of actual seasonal yields from calculated straight line and parabola trends of the crops in specified rotations.*

Rotation No.	Crop	Av. yield in bushels per acre	Straight line trend	Summation of deviations of actual and calculated values of y	
				Straight line trend	Parabola trend
1	Wheat	52.9	+1.26	332.0	296.1
1	Oats	63.5	+1.26	361.0	365.4
3	Wheat	56.4	+0.96	287.9	268.2
3	Oats	56.1	+0.46	419.5	399.7
4	Wheat	52.5	+0.63	227.9	205.6
4	Oats	42.3	−0.52	240.5	236.2

While it is valuable to demonstrate that the yield data shows unequal trends for the period covered, the parabola trend is difficult to visualize and, as has previously been discussed, is for that reason less usefull for the presentation of trend relationships to the layman than straight line trends. The slope of the straight line is determined by only one unknown, a, while the course of a second order parabola is determined by two unknowns, a and b. The unknown c in the equation determines the point of origin or the y intercept of the curve. Somewhat better fits than obtained could be secured by the use of a third order parabola. It is doubtful, however, if the slight improvement in the closeness of fit would justify the extra calculations involved.

The parabola trend has one decided fault in its application to the rotation yield data here presented in that it produces a curve tending downward at increasing rates towards the end of the cycle. The actual yields give no evidence of the occurrence of such dips but rather show that they may be maintained at around their present levels. At any rate, either increases or decreases, as the case may be, will be gradual rather than at accelerating rates.

VARIABILITY OF SEASONAL YIELDS

The comparative variability of the seasonal yields of separate crops or of plats receiving different treatments serves as an index of the reliability of such yields. Klages[3] made use of the seasonal variability of yields in relation to crop adaptation studies. The axiom was established that the ecological optimum of a given crop was approached

[3] KLAGES, K. H. W. Geographical distribution of variability in the yields of field crops in the states of the Mississippi Valley. Ecol., 11: 293–306. 1930.

————. Geographical distribution of variability in the yields of cereal crops in South Dakota. Ecol., 12: 334–345. 1931.

in those particular locations where the yields of the crop in question were found to be uniformly high and showed a low degree of variability.

The variabilities in the seasonal yields of the various crops included in the rotation systems at Moscow from 1915 to 1937, as evaluated by the coefficient of variability, are given in Table 1. When considered in the light of their respective probable errors and on the basis of significance, most of the values are remarkably alike, yet some interesting differences are in evidence. The wheat yield in rotation 4 shows a significantly lower degree of variability than that of the oats. The same is true also in a comparison of these two crops in rotations 6 and 8. The potato crop in rotation 8 gives the highest variability of any of the crops grown. The relatively low yields and high degree of variability of this crop would indicate that potatoes are not especially well adopted to conditions prevailing in the Palouse area.

SUMMARY

Variability studies of seasonal yields may be expected to be of value to supplement yield data in cases where a sufficiently long enough period is covered by the experiment for definite statistical analysis. They are especially desirable in the analysis of the yield data of experiments extending over a period of 25 years or more.

Trend relationships of the yield data of 10 crop rotation systems conducted on the University Farm at Moscow, Idaho, are presented to show that yield data of long time experiments and especially of crop rotation data may be supplemented to advantage by trend studies.

While straight line trends are not applicable to all compilations of yield data, they provide in cases where they fit the data a good index of the general or average slope of the trend line of yield tests extending over a period of years which can be used to advantage in the analysis and presentation of the results. In cases where the date exhibits variable trends for different periods of the experiment, it is necessary to resort to curvilinear trends in order to formulate the trend relationships. In the crop rotation yield data analyzed, the closeness of fit of the yield data to the trend lines was not materially better for parabola than for straight line trends.

NOTE

THE CHALLENGE OF AGROBIOLOGY

THE review of my "A B C of Agrobiology" by "R. B." in the March (1938) number of this JOURNAL raises an issue on which a little comment may be in the general interest. On page 265 the reviewer says:

"In addition to being the A B C of Agrobiology one gets the impression that this book is also the X Y Z of the subject. Its problems are solved! The job is done. Its laws are all discovered. They are immutable and universal; . . . ."

In the first place, the reviewer is assured that this is very nearly, if not quite, the impression that the book was intended to convey.

In the second place, the half-derisive tone of the review seems to indicate that the reviewer himself entertains no conviction that the problems of agrobiology have been solved, that its job has been done, that its laws have been discovered, or that, if there are any laws of agrobiology, these laws have any claim to universality or immutability.

If this aloofness were only the reaction of a single individual it would scarcely call for notice, but the author has had ample occasion to note that it reflects the state of mind of many plant biologists and agronomists. The vastness of the plant world, the diversities of characters of plant species, and the number and variability of the environmental influences that affect the growth and yield of plants have induced an age-old feeling that here is a great tangle which it were presumptuous to expect any man or set of men to untangle. Most incredible of all appears to be the assertion that the quantitative phenomena of plant life are reducible to a single universal rule that partakes of the nature of an immutable law of Nature.

In committing themselves to the principle of universality and immutability agrobiologists are well aware that they are suspending their basket of eggs by a single thread which any passer-by may essay to cut. For, let there be found a single authentic exception to the rule of universality, and the whole agrobiologic proposition is done away. The universality here contemplated is contained in the theorem that the nutrition and growth of all plant types, without known exception, are controlled and directed in a determinate manner by the mass action law.

The purpose of this note is to indicate a simple experiment by which anyone may try his hand at blowing up this proposition and with it the whole tribe of agrobiologists. Let there be prepared a series of equal portions of a normal soil. Let there be grown in each of these portions of soil the same stand of *any* pure bred plant genotype or stabilized agrotype under the varied influence of graded amounts of *any* recognized factor of plant growth. (Note that the reference to *any* plant type and *any* growth factor gives full scope to the principle of universality.) If the resulting series of yield figures do not fit accurately in the agrobiologic yield equation $\log(100-y) = 2-0.301x$, then the agrobiologic basket is hopelessly smashed. If the fit is accurate, then the whole case for agrobiology is fully proved because any

plant and any growth factor, i. e., all plants and all growth factors, will have given the answer.

The whole argument is thus reduced to a question of the validity or invalidity of a single working equation, and this is a question that can be resolved experimentally. If the equation does not hold for any case, there is nothing more to be said. If it holds in every case, the vital principles of agrobiology, including the law of the constancy of the effect factors of growth factors, the inverse yield-nitrogen law, the concept of plant life as a definitely limited quantity, and the whole system of the new agrobiologic dynamics by which the quantitative reaction of plants to the positive factors of their growth can be calculated in advance, *et cetera*, become fully established because the validity of each and all of these agrobiologic fundamentals is guaranteed by the validity of the parent mass action equation.

It will perhaps be natural to ask, How did the agrobiologists acquire confidence (or cock-sureness, if you will) in their conclusion that the main problems of agrobiology have been solved? This confidence is founded on a record of experimentation and research in many countries, both temperate and tropical, by many investigators who have worked with practically all plant species of economic importance. The suggestion that plant nutrition and growth are the result of a mass action of the classic type was put forward 30 years ago by Mitscherlich, who to date has made nearly 8,000 controlled experiments that have consistently verified the suggestion. Mitscherlich's lead has been followed by contemporary workers both academic and practical who have clarified and expanded Mitscherlich's original concept and have multiplied the number of his experiments manyfold.

It is not denied that some investigators, including at least one American biochemist of Welsh extraction, have offered experimental refutation of the Mitscherlich theorem. Agrobiologists have a certain standard of experimental accuracy and precision that they impose on their work. These standards include recognition of the fact that plant growth depends on all its positive factors (not one can be missing); that hostile negative factors must be excluded from the environment; that the law of conflicting attributes of growth factors must be respected; that experimental conditons must be uniform and constant; and that the test plants or seeds must be uniformly viable. Agrobiologists cannot quarrel with the results of such an experiment, but they need not be expected to accord respect to work (past, current, or future) that does not measure up to this standard.

In view of what an established agrobiology has to offer, no agronomist charged with the public duty of promoting effective farming practices, and no conscientious teacher of the principles of plant nutrition, will be justified in neglect in orienting himself for or against the tenets of agrobiology, preferably by intelligent experiment or at least by an open minded examination of the record.—O. W. WILLCOX, *Ridgewood, N. J.*

BOOK REVIEW

AGRICULTURAL ANALYSIS: A HANDBOOK OF METHODS EXCLUDING THOSE FOR SOILS

By C. Harold Wright. London: Thos. Murby & Co. VII+343 pages, illus. 1938. 16/.

THE title of this book indicates clearly its purpose and content. Designed as a laboratory manual for agricultural analysts with limited library facilities, the book gives methods of analysis of fertilizers, feeding stuffs, milk, milk products, insecticides, and fungicides, together with references to sources of information. It also describes the preparation of the indicators and standard solutions called for in the various procedures and data necessary for calculating results.

Both official methods and alternative methods are given, except where one method is deemed much superior to others. Special attention is given to recent developments, such as determinations for the mineral constituents of feeding stuffs and to the analysis of derris and pyrethrum.

Tables of the International atomic weights and of gravimetric and volumetric factors and their logarithms and an index of authors and subjects add materially to the value of the book. (J.D.L.)

AGRONOMIC AFFAIRS

MEETING OF AMERICAN SOYBEAN ASSOCIATION

THE annual meeting of the American Soybean Association will be held at Wooster and Columbus, Ohio, September 12, 13, and 14, for the primary purpose of summarizing important facts regarding the growing and utilization of soybeans.

The meeting will convene at noon on September 12 at the Experiment Station at Wooster and will include an inspection of the soybean investigations of the Agronomy Department and of animal feeding experiments which involve the use of soybeans.

On September 13 and 14 the group will meet at Columbus for an inspection of field plat experiments with varieties and cultural practices for soybeans and of exhibits of machinery for soybean growers, industrial products made from soybeans, and soybean products for human food. A program of papers dealing with recent developments in the growing and utilization of soybeans will also be arranged.

For further details on this meeting, write to Professor J. B. Park, Department of Agronomy, Ohio State University, Columbus, Ohio.

MEETING OF WESTERN BRANCH OF SOCIETY

THE Western Branch of the American Society of Agronomy will meet at the University of Arizona, Tucson, Arizona, August 31 to September 2. For further details concerning the meeting, write Ian A. Briggs, Secretary, Western Branch of the American Society of Agronomy, University of Arizona, Tuscon, Arizona.

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MEASURING CROP YIELDS ON A COMMUNITY SCALE[1]

FRED S. REYNOLDS AND ALBERT E. COLDWELL[2]

WHEN the Soil Conservation Service demonstration project Tex-3, near Dalhart, Texas, had been in operation for about three years it was apparent to the project staff members that satisfactory results were being obtained by methods of water conservation, the chief of which were contour farming and terracing. However, it was felt that these observations alone were not sufficient to convince many persons except those who had the opportunity to visit the project and inspect the results. So a method of measuring the yield of grain sorghums on all the fields in or near the project area was devised, and the information gained was significant enough to justify an explanation of the method and an analysis of its accuracy.

This paper is not intended to enter the field of research, as the yield measurements were made for only one year. It is planned to repeat them each year but conditions will not be controlled from year to year. Hence it is felt that the value of the measurements lies in the large acreage which they represent.

The object was to perfect a dependable, quick, and practicable method of measuring crop yields of fields ranging up to 640 acres or sometimes larger. The plan must be applicable to any size field of any shape, regardless of the number of acres. In other words, the rate of yield is the information sought. The total yield of a field is then found by multiplying the number of acres by the rate of yield per acre. Although the accompanying results are for sorghums only, the same method, with slight modifications, could be used for small grains.

The yield measurements in 1937 were made primarily to evaluate the terracing and contouring practices being advocated by the Soil Conservation Service. Secondary in consideration were comparison of soil types in yielding capacity and effectiveness of various crop residues in controlling wind erosion. As the work progressed refinements were added, and it is believed that the same measurements

[1]Contribution from the Soil Conservation Service, Dalhart, Texas. Received for publication April 5, 1938.

[2]Associate Agronomist and Junior Engineer, respectively.

can be made more accurately next year by including all these improvements from the beginning of the season.

The Soil Conservation practices being followed by the cooperators and many other farmers need to have an economic value placed on them. In order to do this the grain sorghum yields on the farms of the Dalhart area were measured. So far as known, there was no method commonly used on a large field scale to do this. Measurements were made on 63 fields in the area consisting of 11,485 acres with a variation of soil types and farming practices being followed. These were grain sorghums and had to be measured after the grain was matured and before harvest. This period is normally from October 1 to November 15; therefore, any method used had to be quickly applied.

There is need to know the productive capacities of the various soil types. The terraces and other mechanical structures need to be evaluated also. It is believed, therefore, that the Conservation Service was fully justified in going to the nominal expense of measuring these yields, which in turn serve as a basis for studying effectiveness of the practices.

With this method it is believed that the present staffs on the Soil Conservation Service projects can, if the need arises, measure the yields on all the fields under agreement and many others in addition.

County agents may use this method quite effectively in promoting terracing, contouring, and other desirable farm practices in their counties, by organizing 4-H clubs to measure the yields on all terraced and contoured fields and as many or more untreated fields to be used for comparison. This brings out the real merits of a type of treatment in such a way that farmers can readily grasp them.

PLAN OF WORK

To begin with, the idea of sampling a field many times was uppermost in mind. In order to carry out this idea, three fields, one terraced and two straight-rowed fields, all representative of the area, were selected to try out various modifications of the sampling theory on each field.

The equipment used consisted of a record sheet for recording the field work (Fig. 1), pencil, a 5-foot measuring rod with inch graduations, a pocket knife, and a shoulder sack for collecting samples.

Rules for sampling on a field were as follows: (a) Roughly divide the field into three or more equal lengths or segments. (b) Go straight across the field in the center of each of the equal segments and at approximately right angles to the direction of the rows. (c) Stop at the 24th row and measure off 10 feet of the 24th and 25th rows. (If the rows are not perpendicular to the path followed use a paced distance equivalent to 24½ rows.) Do this in such a way as to eliminate the human element. For instance, always measure to the same side. (d) Collect the first five heads of the 10-foot segment of the two rows and put in the sack to be taken in for weighing. (e) Count all the heads in the two-row 10-foot segment and record. Also record number of heads taken, for many times there will be less than five heads. (f) Then

CROP YIELD SURVEY

Name__________ Date__________ Field______ Sheet No.____

How Farmed__________ Direction________ Part of Field________

Made Count on________ No. Rows______ Feet______ Acres in Field____

Surveyor__________ Total Heads________ Total Heads Taken________

Green Wt.______ Dry Wt.______ Length of Sample Area________

No. count		No. Heads	Heads Taken	No. Stalks	Height Inches	Terrace No.	Distance from Nearest Terrace Above or Below		Crop and Variety
1	22								
2	23								
3	24								
4	25								
5	26								
6	27								
7	28								
8	29								
9	30								
10	31								
11	32								
12	33								
13	34								
14	35								
15	36								
16	37								
17	38								
18	39								
19	40								
20	41								
21	42								

Mark through numbers not used

FIG. 1.—Typical record sheet for field work.

proceed again across the field with the count of 1 until the 24th and 25th rows are reached, and so on across the entire field.

DISCUSSION OF RESULTS

The above method was modified on the three fields with the results given. At first four apparently average heads were taken, but this was thought to be inaccurate by allowing the human element to enter in. Table 1 gives results of from two to five yield measurement tests on each of the three fields.

TABLE 1.—*Results of yield measurement tests on three fields.*

Field	Yield of headed grain, lbs. per acre — No. heads taken for weight — 2 rows 10 ft. long: 4	5	All for 10 ft.	2 rows 20 ft. long: 5	10	All for 10 ft.
Bill Roper, 46 acres	——	2,067	2,095	2,111	——	2,140
C. J. Roberts, 160 acres	1,190	——	1,152	——	——	——
J. M. Hester, 80 acres:						
Oct. 12	456	——	490	——	——	——
Nov. 3	——	——	——	393	412	——
Omitting block method	——	——	——	——	——	——

Field	Yield of headed grain, lbs. per acre: Block method	Average of all trials	Percentage of variations from average yields
Bill Roper, 46 acres	——	2,103	±1.06
C. J. Roberts, 160 acres	——	1,171	±1.62
J. M. Hester, 80 acres:			
Oct. 12	518	——	——
Nov. 3	——	454	±9.03
Omitting block method	——	438	±8.44

By referring to Table 1 it is seen that Roberts' and Hester's fields were measured to compare yields from four average heads with that from all the heads for the 10-foot samples. Roberts' yield was 1,190 for the four-head sample and 1,152 for the 10-foot samples. However, Hester's was smaller for the four-head samples as compared with the 10-foot sample, being 454 and 490, respectively. Since trying to select four average heads was slow and introduced the human element, it was abandoned. Therefore it was decided to try taking the first five heads that the operator came to in each sample area. This is equivalent to picking the heads at random. Another reason for taking five heads was to increase the number of heads taken for weighing and to expedite the work of taking the samples. The operator can rapidly cut

the first five heads and put them in his sack without hesitating to estimate mentally if they are of average size.

Roper's field was also used to compare results with several modifications of the sample method. The operator took five heads, then all the heads for 10 feet, for weighing, then counted the heads on an additional 10 feet or a total of 20 feet in a sample area. Then the calculations were made on the following basis:

A. 5 heads on 10-ft. basis.
B. 5 heads on 20-ft. basis.
C. All heads for 10 ft. on 10-ft. basis.
D. All heads for 10 ft. on 20-ft. basis.

The results ranged from 2,067 to 2,140 pounds per acre, or an average of 2,103.25 pounds.

The field had 46 acres and was sampled 27 times, or once to every 1.7 acres. It is believed that 2,140 pounds is nearer the actual yield than any other figure because this is based on a 20-foot length of sample with all the heads for 10 feet of this length being harvested for weighing. It is obvious that the more samples taken and the larger the individual samples, the more accurate the results. Roper's field was one of the heaviest yielding of those measured; likewise one of the most uniform throughout.

Continuing the discussion of the five-head sample, it is to be seen in Hester's 20-foot length sample that five heads gave 393 pounds as compared with 412 pounds for the 10-head sample. Observe that this is the same field mentioned previously where the yield was 454 pounds and 489 pounds, respectively, which was taken several weeks earlier.

Hester's field varied from 393 pounds to 518 pounds in the five trials made for the purpose of developing a yield measurement plan. This difference of 125 pounds, or about 25%, is entirely too great to pass up without further comment. The block method giving 518 pounds was the highest. Briefly, this method is so designated from selecting four blocks of 2,500 square feet each, one near each of the four corners of the field, and harvesting all the heads in each block for weighing and calculating to an acre basis. This was slow and cumbersome and necessitated the harvesting of too great a yield and permitted the human element to creep in. However, the human element could easily be removed by previously plotting the field and predetermining the location of each block. Too few samples are secured by this method, so results would not be representative in most of the fields with only four blocks or samples taken, therefore this method was discarded. Studies were continued, however, on the basis of the smaller samples in large numbers widely and uniformly distributed over the entire field, with the belief that this procedure gave more promise than any other.

The remaining four yields of the Hester field of 454, 489, 393, and 412 pounds, respectively, are analyzed further in Table 2 to determine why heavier yields were obtained in October than in November.

A study of the figures in Table 2 may be made by comparing the October yield of 490 pounds with the 412 pounds of November, for

TABLE 2.—*Analysis of repeat sampling on Hester field to determine factors responsible for variation in calculated yields.*

Factors considered	Harvested Oct. 12		Harvested Nov. 3	
Calculated yield, lbs. per acre	456	490	393	412
No. heads per sample area, reduced to 20 ft	13.84	13.84	11.67	13.78
Average weight of heads, lbs.	0.1040	0.1116*	0.1062	0.0944*
Weight of heads per sample area, lbs.	1.44	1.54	1.24	1.30
No. of areas sampled	38	38	18	18
No. of heads weighed	101	263	80	143
Total No. of heads in areas sampled	263	263	210	248

*Difference in these two figures is factor responsible for difference in yield, but no explanation can be given for it.

the reason that these two yields are based on the larger number of heads for each of the dates.

The field was quite spotted, in which case repeat tests could be expected to vary. Furthermore, the October trials included 38 sample areas, while the November one had only 18.

The fact that the November tests were made 22 days after the October tests might be thought to have permitted the heads to dry out, but all samples were dried to a constant weight for calculations so this should not have been a factor here.

In order to speed up the yield measurements during the last part of the field work a change was made by taking samples on the 49th and 50th rows, measuring 20 feet for the sample area and taking only five heads for weighing as before.

A study was made to determine whether it was necessary to make observations as close as every 24 and 25 rows or whether they might be widened to 49 and 50 rows, thus reducing the field work perhaps a third. By taking samples on the 49th and 50th rows and crossing the field at quarter mile intervals, one man can measure the yields on 300 to 500 acres of grain sorghums a day. For this study eight fields, four of which were spotted and four quite uniform in yields, were selected for further analysis as reported in Table 3.

Only one survey was actually made of each field on the 24th and 25th rows. The figures for the 49th and 50th rows were arrived at by using the even numbers 2, 4, 6, etc., omitting the odd numbers of the survey.

It will be seen that the spotted fields varied from +10.7 to —23.9%. The uniform fields had less variation, ranging from +6.7 to —6.2%. This indicates that it is necessary to take more observations on the spotted fields, while the uniform fields need not be sampled as many times to arrive at the approximate yields.

It may safely be said that the accuracy of these yield measurements varies directly with the uniformity of the grain throughout the field. That is, the results from the more uniform fields are more accurate than those from the less uniform ("spotted") fields.

Tests made on a theoretical field with exceedingly "spotted" yields scattered throughout the field at random indicate that this method of sampling is correct to within ±20%, and because of the

TABLE 3.—*Comparing yields obtained by sampling the 49th and 50th rows with that taken on the yields obtained on the 24th and 25th rows, all calculations based on the yields obtained on the 24th and 25th rows.*

Fields	Pounds per acre		Variation of 49th and 50th rows from 24th and 25th rows	
	Rows 24 25	Rows 49 50	Pounds per acre	Percentage based on 24th and 25th rows
Spotted Fields				
Taylor, 461	250.5	190.6	−59.9	−23.9
Mitchell and Robison	399	425	+26	+6.5
C. A. Petty	765	847	+82	+10.7
C. J. Roberts, north of house	889	848	−41	−4.6
Uniform Fields				
Bill Roper	2,067	1,939	−128	−6.2
W. H. Green	1,568	1,481	−87	−5.5
Peden N. W. ¼	1,149	1,226	+77	+6.7
Knight Sec. 16	918	958	+40	+4.4

fact that none of the fields are as spotted as the theoretical one, the yields on which ranged from 0 to 1,500 lbs. per acre, it is believed that the actual results are in the main accurate to within ±10% and ±5% in most cases.

Actual field measurements to determine comparative accuracy bear out this contention. On a field with high yield, which necessarily indicates uniformity, repeat samples varied less than ±2% from the average results, whereas on a "spotted" field the repeat samples varied as much as ±9% from the average. (See Table 1.)

The question, "How near are the calculated yields to the actual harvested yields?", has been repeatedly asked. There are so few fields where the entire yields were segregated and measured that this question can not be definitely answered in most cases.

Where estimates by farmers based on some form of measurements were made, they agree pretty well with calculated yields. There were one or two, however, who questioned the calculated figures, claiming their harvested yields did not agree with the survey figures.

It was found that estimates or guesses varied widely from calculated yields, ranging from below to far above, as might be expected. In the majority of the cases estimates are in round numbers such as 1,000, 1,500, or 2,000 pounds per acre.

It is interesting to note how one farmer, "D", over-estimated one field by estimating 2,500 pounds for a field calculated to be 1,650 pounds, and made a greater error in the opposite direction by estimating 635 pounds for a field calculated to be 1,568 pounds. Both fields were later combined with the actual production in line with calculated yields. Another field was surveyed at 46,270 pounds while yet

in the field. The owner later reported that he headed it and sold the entire amount, 23 tons, or 46,000 pounds.

At the time of making the survey a few were asked to estimate their yields so that their figures could be compared with the results of the survey. Table 4 gives the results of the information thus obtained.

TABLE 4.—*Comparing owner's estimate with calculated yield on five fields.*

Farmer	Acres	Owner's estimate		Calculated		Variance of estimate of total amount from calculated	
		Acre yield, lbs. per acre	Total amount, lbs.	Acre yield, lbs. per acre	Total amount, lbs.	Minus	Plus
A, Heiskell	70	1,220	85,400	1,457	101,990	———	16,590
B, Blades...	240	700	168,000	744	178,560	———	10,560
C, Peden...	500	1,500	750,000	964	482,000	268,000	———
D, Green...	55	2,500	137,500	1,650	90,750	46,750	———
Green	27	635	17,145	1,568	42,336	———	25,191
E, Ritchey .	——	———	46,000 sold	661	46,270	———	270
Totals ...	892	———	1,158,045	———	895,636	314,750	52,611

It will be observed that some over-estimate while others under-estimate the yields. The estimates however, are far too unreliable to be used as a yard stick in measuring the value of soil conservation practices. The average number of acres represented by one sample was 3.7. However, this figure varied from 1 acre to 11 acres while measuring yields on a little more than 11,000 acres.

This method of measuring yields is well adapted to grain sorghums, but modifications would probably have to be applied in order to measure small grain or grass yields. The sample areas would have to be smaller, and probably the whole crop in each sample area should be harvested. However, no matter what crop is to be measured, it is felt that the suggestions outlined for dividing the field into parts and calculating yields to an acre basis will be of value.

SUMMARY

1. A method of measuring crops and grass yields while still in the field is needed.

2. The farm practices, such as furrowing, ridging, contouring, and terracing, on ranch and farm lands need to be evaluated.

3. A method of calculating yields was perfected. The method is based on securing a large number of small samples uniformly distributed so that all parts of the field are proportionally represented.

4. The samples are weighed and yields calculated to an acre basis.

5. On fields from 80 to 640 acres, one sample should represent not more than from 3 to 5 acres.

6. Each field to be surveyed should be observed for kind of crop, shape and approximate size, and a route of march to obtain samples decided upon.

7. The actual samples should be chosen in such a way that the human element is reduced to the minimum.

8. The more uniform the crop, the more accurate the calculated yield will be. Therefore, fewer samples are required from the heavy yielding fields, which are also uniform, than from spotted and light yielding fields.

9. Calculated yields may safely be said to be within ± 10% of the actual yield.

10. Farmers' estimates are not sufficiently accurate to be used as a yard stick in measuring the value of soil conservation practices.

11. One man can measure the yield on 300 to 500 acres of grain sorghums a day.

A PROMISING WILT-RESISTANT LONG STAPLE COTTON[1]

D. C. NEAL AND C. B. HADDON[2]

A SELECTION of Delfos cotton made at the Northeast Louisiana Experiment Station, St. Joseph, Louisiana, by the junior author, in 1934, has exhibited marked resistance to fusarium wilt in tests conducted for the past three years on the heavily infested wilt plots at Baton Rouge, Louisiana.

In a test of 16 varieties of cotton in 1936 at Baton Rouge for wilt resistance it was noted that this selection of Delfos was one of the outstanding wilt-resistant varieties, with productivity also fairly good. In a further test of 10 new strain and hybrid cottons for wilt resistance in 1937, the Delfos selection, namely, Delfos 2323-965-425, remained almost free of wilt throughout the season, showing, as late as September 8, only 0.5% infection of a total population of over 600 plants. In comparison, Half and Half, a susceptible variety with a population of 516 plants, developed approximately 63% wilt. In one series, comprising row sections 100 feet long in which the above varieties were compared, Half and Half developed 100% infection by September 8, while the Delfos remained entirely healthy (Fig. 1).

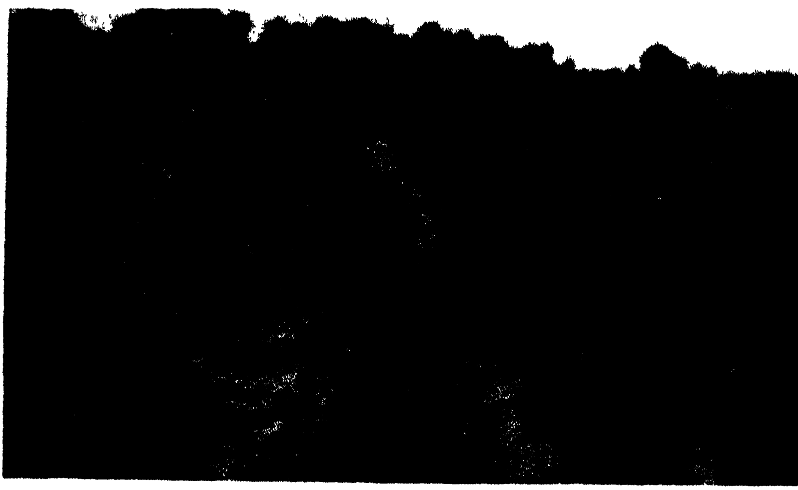

FIG. 1.—Wilt infection in new strain and hybrid cottons at Baton Rouge, La., in 1937. Left, Stoneville X D. P. L. 4-8; center, Half and Half; right, Delfos 2323-965-425. Photographed August 4.

This wilt-resistant selection was originally made from a plant of Delfos 2323-965 cotton which remained healthy throughout the season of 1934 in an infested area on the experiment station plots at

[1]Joint contribution from the Bureau of Plant Industry, U. S. Dept. of Agriculture and the Louisiana Agricultural Experiment Station. Received for publication April 9, 1938.

[2]Senior Pathologist, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Superintendent, Northeast Louisiana Experiment Station, respectively.

St. Joseph, Louisiana. The selection grew vigorously producing a normal crop and fruiting about as early as any of the Delfos plants not in the infested area. The staple length was 1 5/32 inches full. In 1936, the seed from the selection was again planted in the wilt area and again it remained healthy throughout the season, producing a splendid yield of 1 3/16-inch cotton.

YIELD, STAPLE LENGTH, AND FIBER UNIFORMITY

On the "bench" or "bluff" soils at Baton Rouge this cotton has produced over 1,100 pounds of seed cotton per acre, following moderate applications of an N.P.K. fertilizer. At the Northeast Louisiana Delta Experiment Station, where it was included in a variety test for the first time in 1937, the yield has been in excess of a bale per acre (Table 1). The staple averages 1 1/8 inch on bluff soil and from 1 5/32 to 1 3/16 inch in the Delta. The lint averages about 32.5%. Combings of seed locks collected from 16 bolls near the middle portion of individual consecutive plants in a row show that the fiber possesses good uniformity (Fig. 2).

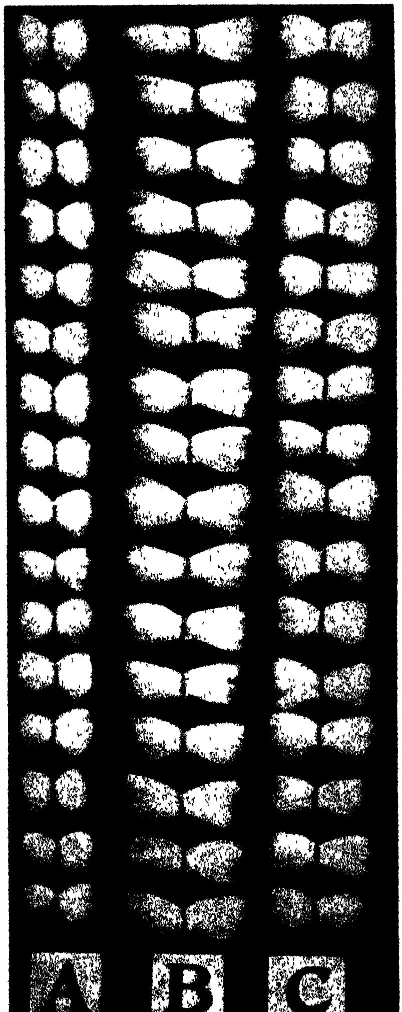

Fig. 2.—Comparison of staple length and fiber uniformity of one susceptible and two wilt-resistant varieties of cotton grown at Baton Rouge, La., in 1937. A, Half and Half; B, Delfos 2323-965-425; C, Dixie-Triumph P -32.

PLANT TYPE

The selection is fairly representative of the Delfos 6102 type in growth habit, rapidity of fruiting, leaf characters, boll size, and fiber properties. It is unlikely that it is a natural hybrid.

AVAILABLE SEED SUPPLY

At the present time, as would be expected, very little seed of this strain is available. However, plans are now being made to increase it as rapidly as possible for ultimate release to growers chiefly in the wilt-infested districts of the Delta. Sufficient stock should be available in 1939 for planting approximately 150 acres of this selection.

TABLE 1.—*Comparison of yields of Delfos 2323-965-425, a wilt-resistant selection, and six standard varieties at St. Joseph, La., in 1937.*

Variety	Seed cotton per acre, lbs.
Delfos 2323-965-425, Wilt Resistant	2,246
Washington (Delfos 719)	2,130
Ambassador (Stoneville 4A)	2,321
Delfos 9252	2,110
Ark. Acala 1114	1,902
Rowden 2088	2,096
Delfos 130	2,588

GENERALIZED STANDARD ERRORS FOR EVALUATING BUNT EXPERIMENTS WITH WHEAT[1]

S. C. SALMON[2]

GENERALIZED probable or standard errors have often been used for evaluating the results of field experiments for the reason that they are believed to be a better measure of random variation than can be derived from the small number of plats of each variable characteristic of such experiments. Those who first used this device seem to have clearly realized that it provided approximate values only and that certain assumptions were involved which might or might not hold true.

Curiously enough, in the light of later developments, it formerly was quite generally assumed that the random error was highly correlated with yield or whatever was being measured. Thus, the characteristic feature of the "deviation of the mean" method devised by Hayes (4)[3] consisted of expressing the standard error or probable error as a percentage of the mean yield, which was then applied to the yield of each individual variable. The validity of this procedure obviously depended upon the above assumption. Hayes and Immer (5) presented evidence for such a relation in varieties of wheat, but later in a more extensive study involving several crops, Immer (7) found none.

With the advent of analysis of variance, all thoughts of a possible relation between standard error and yield and other metrical attributes seem to have vanished. At least those who advocate this method seldom or never mention or emphasize the assumptions on which validity depends, nor is the degree to which they actually are realized in particular cases seriously considered. Furthermore, it appears to be assumed that by this method an accurate estimate of random error for any and all properly conducted experiments is assured.

Altogether the current situation with respect to the use of generalized estimates of random error can be characterized as nothing less than anomalous, as may be seen from a consideration of the manner in which analysis of variance has been used and the problems to which it has been applied. Thus, several workers in recent months have used it to interpret various disease-resistance trials with small grains in which a single error term is derived and applied to all varieties indiscriminately regardless of the range of infection between varieties. This range in some cases has varied from 0 or near 0 to 75 or 80%.

If it is not clear that the standard errors for varieties immune from or highly resistant to disease are materially different from those for varieties in which, say, 50% of the plants are infected, a casual consideration of the binomial formula for standard error will show that such is quite certain to be the case. The binomial, it may be noted, is

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[3]Numbers in parentheses refer to "Literature Cited", p. 662.

usually considered especially applicable to discrete data such as those being considered in which the plants fall into two categories, those that are diseased and those not diseased. As shown by this formula the relation between standard error and infection is curvilinear, the standard error being a maximum with 50% infection and 0 with 0 and 100% infection. The situation is further complicated by the fact, as will be shown later, that in some cases—perhaps in many—neither the binomial nor generalized errors derived by analysis of variance as applied in the usual way can be considered as valid estimates of random error.

Also, certain workers recently have applied a single error term derived by analysis of variance to field crop data from several locations and extending over a period of years without any attempt to show that the errors are in fact the same for all locations and years. Anyone familiar with field plat experiments knows they often are not. Apparently, analysis of variance has often been used in such cases without realization on the part of the user that any assumptions as to similarity of variance or standard errors were involved.

The primary purpose of the present paper is to indicate the relation between standard error and infection in certain experiments dealing with resistance of varieties of wheat to bunt, to illustrate some of the difficulties attending a statistical analysis of such data, and to point out some of the serious errors almost certain to result from a blind, indiscriminate use of current statistical methods for such data. An attempt also will be made to analyze the data statistically by what is believed to be a sound, reliable procedure, but, as will appear later, a critical consideration of the proper methods to apply is in the main left for the attention of others.

MATERIALS AND METHODS

The data used in the present paper were obtained by Rodenhiser and Holton (8) as a part of their studies with physiologic races of bunt. The general description of the tests and the technic employed has been given by them. Briefly, the latter consisted of growing duplicated short rows (5 to 8 feet) of each host tester, the seed having been inoculated with spores of the desired collection of bunt. A single row of each variety inoculated with each collection of bunt was seeded and the entire seeding was then repeated in the same order. In other words, the duplicated rows were systematically distributed throughout the experimental area. Infection was recorded as a percentage of the total number of heads counted at or near harvest time. The number counted was seldom less than 200 and was sometimes more than 400 per row.

A dozen or more tests of the kind considered herein have been conducted during the past five or six years, but because of unfavorable soil or weather conditions at or soon after seeding, a satisfactory degree of infection and uniform infection has not always developed. For the purpose of this study, five experiments were selected on the basis of high infection in the susceptible varieties and reasonably uniform infection throughout the experiment. Both winter and spring wheat have been included. The varieties used as host testers, the location of the tests, and other details regarding them are given later in tables in connection with the experimental data.

The first objective of the study was to determine the magnitude of the error introduced by calculating a generalized standard error for all varieties. It appeared that this could be done by calculating separate standard errors first for each variety and second for each collection of bunt. It soon appeared that the objective could be attained from a comparison of the varieties of wheat alone, and the calculations for collections of bunt were discontinued and none of the results pertaining thereto is presented. The standard errors were calculated by analysis of variance and thus measure the fluctuation of the members of each pair of rows about the mean of each pair. If this method is not accurate when applied to a group of varieties, neither is it accurate when applied to a group of collections of bunt on a single variety which differs materially in its reaction to the different collections of bunt. Certain ones of the varieties in the present study do differ in this respect and this fact should be considered in interpreting the data. However, it is believed to have no important bearing on such conclusions as are arrived at herein.

EXPERIMENTAL RESULTS

In order to indicate the nature of the basic data used in the calculations, a skeleton table giving the results with 20 collections of bunt from the test with winter wheat varieties at Kearneysville, W. Va., in 1935, is presented in Table 1. Altogether 69 collections of bunt were included in this experiment, of which the 20 in the table are representative. The names of the varieties of wheat used are given in the first row at the top of the table and the designation of the collections of bunt in the first column on the left of the table. The two columns of figures under each variety name are the recorded percentages of bunt for each of the duplicated rows of each collection. At the bottom of the table are given the average percentage of bunt for all 69 collections for the first and second replications separately and also for each variety.

The average percentage of bunt for each variety of winter wheat for each of three locations and the standard error calculated separately for each variety are given in Table 2, and similar data for spring wheat at two locations are given in Table 3. The number of collections of bunt, which is also the number of pairs of duplicate rows on which the calculations for each variety are based, was 69 for Kearneysville, W. Va., 74 for winter wheat at Pullman, Wash., 48 for winter wheat at Bozeman, Mont., in 1934, 45 for spring wheat at Bozeman in 1933, and 55 for spring wheat at Pullman in 1935. The number of heads (N) counted per row is given in parentheses for each location.

It will be noted that the standard errors are very different for different varieties. Thus, at Kearneysville, the standard error for Turkey is nearly 9 times as great as that for Hohenheimer. At Pullman for winter wheat the largest standard error is more than 3 times the smallest; at Bozeman for winter wheat the ratio is more than 5, and for spring wheat 18; and at Pullman for spring wheat more than 2. It should require no additional data or argument to make it clear that the use of a generalized standard error derived by analysis of variance (or in any other way in which all data are pooled as in analysis of variance) to be applied to all varieties alike would lead to very erroneous conclusions.

TABLE 1.—*Relative infection in different varieties of wheat with 20 collections of bunt at Kearneysville, W. Va., in 1935.*

Bunt collection No.	Hybrid 128		Turkey		Min-turki		Oro		Ridit		Albit		Martin		Hohen-heimer		White Odessa		Hussar		Average percentage of bunt
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
1	86.6	80.7	8.3	6.5	79.1	72.8	0.0	0.9	6.3	3.9	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.5	0.6	17.5
2	76.4	95.2	89.0	84.3	90.6	84.3	2.5	3.6	8.7	2.2	92.4	90.6	18.4	16.0	0.0	1.4	97.5	98.1	81.0	74.9	55.4
3	94.9	93.3	3.3	6.0	87.9	75.4	1.5	0.0	6.0	0.7	93.7	90.1	84.5	64.8	0.0	0.0	97.8	94.4	0.0	0.7	44.8
4	91.0	91.7	81.7	87.2	92.0	82.6	1.5	6.3	4.1	3.1	14.0	4.5	0.0	3.0	0.0	0.0	75.9	84.7	0.0	0.7	36.3
5	83.7	90.2	7.5	2.4	60.6	80.9	0.6	1.6	3.9	3.6	4.2	3.2	0.0	2.2	2.4	2.5	0.7	0.0	0.0	0.7	17.7
6	88.9	92.2	5.6	7.4	52.5	39.4	1.1	0.0	2.2	0.0	0.0	0.0	5.0	0.6	0.0	0.0	0.0	0.0	1.6	0.0	14.9
7	97.5	97.9	13.7	9.0	55.6	44.3	0.0	0.8	2.0	1.8	0.0	0.9	1.4	0.8	7.1	0.0	2.0	1.9	0.0	0.0	16.9
7a	81.5	92.2	17.4	9.8	85.4	83.3	1.2	4.4	5.2	4.9	85.2	82.5	61.1	62.0	0.9	5.6	68.8	86.5	1.1	0.0	43.0
8	92.8	91.5	8.5	8.4	30.3	30.4	1.6	1.1	1.2	0.0	0.0	0.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5
9	97.3	92.6	15.4	3.8	17.2	11.7	3.3	0.0	3.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	8.4	0.8	2.5	0.0	12.9
10	93.7	83.3	5.8	1.3	71.2	63.7	3.1	0.0	4.2	3.8	92.0	79.6	77.9	77.0	0.9	0.0	90.4	74.6	1.2	0.8	41.3
11	83.0	77.8	3.8	1.1	70.6	69.9	0.5	1.7	6.8	5.5	2.1	3.9	0.6	0.9	0.0	0.0	1.3	0.0	0.0	0.0	16.6
12	82.1	79.5	9.8	4.7	49.5	75.2	0.0	0.0	15.5	0.0	50.0	76.5	75.5	74.5	0.0	0.0	74.1	79.1	2.8	0.6	37.7
13	80.2	80.7	5.6	10.9	61.9	60.9	0.0	2.0	0.8	10.8	0.6	0.0	2.0	0.0	6.1	12.2	2.1	7.3	1.2	0.0	17.3
14	78.3	77.7	82.5	54.7	76.4	79.7	3.5	7.5	12.7	12.5	81.9	87.2	75.5	76.4	1.1	1.3	88.8	91.2	62.6	67.9	56.1
15	80.0	95.5	10.3	7.3	79.7	83.8	2.4	1.1	10.1	2.2	78.8	90.6	70.1	69.2	0.0	0.0	85.8	98.0	2.1	0.0	43.4
32	85.8	97.8	76.5	92.6	90.9	80.9	59.8	75.0	14.4	5.2	0.0	0.0	2.3	2.1	0.0	0.0	0.0	0.0	1.0	3.3	34.4
51	94.2	95.5	28.3	21.5	45.1	40.0	0.6	1.2	4.8	4.7	0.8	2.6	0.0	0.0	0.0	0.0	5.1	1.4	0.5	0.0	17.4
157	75.0	86.3	52.4	92.1	75.3	85.3	2.2	0.9	1.4	1.0	89.2	85.0	47.0	82.2	0.0	0.0	83.4	90.5	45.5	37.6	51.6
189	87.3	94.6	79.5	92.0	81.1	80.2	7.5	4.7	4.9	6.1	91.9	94.6	71.0	78.0	2.9	1.2	94.6	96.7	53.2	70.2	59.7
Average	87.2	90.7	43.7	46.2	76.9	77.9	3.7	4.4	4.5	4.2	28.5	29.1	23.0	22.5	0.4	0.8	33.3	33.4	10.9	10.6	
Grand average	89.0		45.0		77.4		4.1		4.4		28.8		22.8		0.6		33.4		10.8		

TABLE 2.—*Average percentage of bunt and standard errors for varieties of winter wheat at three locations.*

Variety	Kearneysville, W. Va., 1935 (N = 200)		Pullman, Wash., 1935 (N = 400)		Bozeman, Mont., 1934 (N = 300)	
	Average percentage of bunt, all collections	Standard error	Average percentage of bunt, all collections	Standard error	Average percentage of bunt, all collections	Standard error
Hybrid 128 ...	89.0	4.27	86.1	6.84	78.8	5.59
Minturki.....	77.4	6.98	—	—	—	—
Minhardi. ...	—	—	—	—	60.9	4.59
Turkey.......	45.0	10.17	61.1	9.67	42.7	5.31
White Odessa	33.4	4.97	37.5	8.06	32.1	4.49
Albit	28.8	4.33	28.2	3.75	23.6	4.58
Martin . .	22.3	5.61	23.7	8.46	16.1	2.80
Hussar	10.8	4.41	8.6	5.89	10.3	2.82
Oro .. .	4.1	2.71	6.1	2.45	4.4	2.53
Ridit	4.4	3.63	4.6	3.02	2.8	2.33
Hohenheimer	0.6	1.17	1.9	3.62	1.0	1.05

TABLE 3.—*Average percentage of bunt and standard errors for varieties of spring wheat at two locations.*

Variety	Bozeman, Mont., 1933 (N = 200)		Pullman, Wash., 1935 (N = 400)	
	Average percentage of bunt, all collections	Standard error	Average percentage of bunt, all collections	Standard error
Ulka....	68.2	14.33	90.7	4.26
Mindum.	33.0	9.78	—	—
Marquis...	24.3	7.83	37.7	8.31
Vernal emmer .	21.9	11.19	—	—
Ruby	11.5	5.43	34.7	9.62
Canus...	—	—	25.6	6.59
Garnet	—	—	13.3	5.43
Golden Ball....... .	1.8	1.15	—	—
Hope X Ceres... .	0.8	0.79	—	—

As would be expected there is definitely a relation between average percentage of bunt and standard error. In order to study this relation somewhat in detail, the data for individual pairs of rows were grouped in arbitrary classes according to the average percentage of bunt for each pair of rows, irrespective of variety of wheat and collection of bunt. Those in which no bunt appeared in either row were omitted, since it is clear that the standard error for such rows would be 0. The standard errors of the bunt classes were then calculated as before and are shown in Tables 4 and 5, together with other data to be explained later. A curvilinear relation is so clearly indicated as to invite comparison with the curve derived from the binomial in which $\sigma = \sqrt{\frac{p\,q}{N}}$, where p is the proportion or percentage of bunted heads,

q the proportion or percentage not bunted, and N the number of heads counted. However, as will appear later, the standard errors derived by this formula are much smaller than the observed, and in order to determine whether the forms of the observed and theoretical curves agree, it is necessary to multiply the binomial by a constant, say "a"; that is, $\sigma = a\sqrt{\frac{p\,q}{N}}$.

It is then necessary to choose that value of "a" for each set of data such that the resulting curve will agree most closely with the observed values.

Possibly the most satisfactory way to do this is to choose empirically successive values of "a" and calculate the corresponding values of σ until a value of "a" is found, such that the sum of the deviations equals 0. The labor, while rather tedious, is much less than might be expected. Equations for the curve for each of the five sets of experimental data have been calculated in this way, "a" being calculated to the third decimal, which is as accurate as the curves can be plotted. Each observed standard error was weighted according to the number of pairs of rows entering into its determination. The resulting curves are shown in Figs. 1 to 5, inclusive.

The observed standard error for each of the classes was compared with the theoretical standard error appropriate for the mean infection for each class, as determined by the formula stated above, $\sigma = a\sqrt{\frac{p\,q}{N}}$. The difference between the observed and the theoretical standard error may then be regarded as a measure of the degree to which the curves fit the data. These data for each test, together with the standard error of the differences, are given in Tables 4 and 5.

The agreement between the observed and theoretical curves is surprisingly good for the spring wheat at Pullman and the winter wheat at Bozeman. A considerable number of the discrepancies in the other three experiments are greater than can be explained by random variations, but nevertheless it is clear that the relation approaches that expressed by the theoretical curve.

A logical question is, Why cannot the binomial be applied directly to these data, or in other words, why has it been necessary to introduce the constant "a" in the binomial to make the observed values agree even reasonably well with the theoretical? The answer is that only a portion of the random error is taken into account, *viz.*, that due to simple sampling as the term is used by Yule (11). Bunt infection is greatly influenced by soil heterogeneity and a proper estimation of random errors must account for this source of variation as well.

It appears to be quite generally overlooked that the binomial is strictly applicable only to such problems as drawing marbles out of a bag, or tossing coins in which all the assumptions as to randomness, comparability, etc., are realized, and that it may not be at all reliable for biological data in which observed ratios are often materially influenced by environment. Yule (11, page 259) gives a useful discussion

TABLE 4.—*Comparison of observed and calculated standard errors for different classes of bunt in winter wheat.*

Bunt classes	Kearneysville, W. Va., 1935					Pullman, Wash., 1935					Bozeman, Mont., 1934				
	Number of pairs of rows	Average percentage of bunt	Standard error			Number of pairs of rows	Average percentage of bunt	Standard error			Number of pairs of rows	Average percentage of bunt	Standard error		
			Observed	Calculated	Difference			Observed	Calculated	Difference			Observed	Calculated	Difference
0.1– 2.5%	189	1.2	1.29	1.86	0.57±0.06	206	1.0	1.05	1.99	0.94±0.05	113	1.3	1.13	1.38	0.25±0.06
2.6– 5.0%	75	3.5	2.71	3.16	0.45±0.17	65	3.8	2.54	3.75	1.21±0.17	66	3.7	2.29	2.26	0.03±0.15
5.1– 10.0%	57	7.2	4.34	4.43	0.09±0.29	60	7.0	3.23	5.04	1.81±0.23	32	7.6	2.61	3.20	0.59±0.24
10.1– 20.0%	19	14.2	5.60	6.01	0.41±0.64	12	15.7	8.22	7.17	1.05±1.18	24	14.5	4.12	4.24	0.12±0.43
20.1– 30.0%	6	23.8	8.88	7.33	1.55±1.81	15	24.3	6.89	8.45	1.56±0.92	10	25.5	4.90	5.25	0.35±0.78
30.1– 40.0%	3	33.8	20.14	8.14	12.00±5.84	13	34.0	10.07	9.33	0.74±1.41	14	35.4	4.73	5.76	1.03±0.65
40.1– 50.0%	7	44.6	8.41	8.55	0.14±1.60	14	46.5	16.09	9.83	6.26±2.10	14	45.1	3.41	6.00	2.59±0.47
50.1– 60.0%	6	54.4	23.69	8.57	15.12±4.83	14	54.7	25.18	9.81	15.37±3.40	16	56.4	5.73	5.98	0.25±0.73
60.1– 70.0%	17	65.2	12.57	8.19	4.38±1.52	21	65.7	12.69	9.35	3.34±1.41	37	65.1	7.77	5.74	2.03±0.63
70.1– 80.0%	52	75.9	9.00	7.36	1.64±0.65	24	79.7	13.59	7.92	5.67±1.40	53	75.9	5.45	5.15	0.30±0.39
80.1– 90.0%	116	87.4	5.25	5.71	0.46±0.27	101	85.8	6.18	6.87	0.69±0.33	39	84.7	4.81	4.34	0.47±0.39
90.1– 95.0%	38	92.4	3.43	4.57	1.14±0.29	36	92.4	3.70	5.21	1.51±0.34	1	93.0	2.83	3.07	0.24±1.40
95.1– 97.5%	10	95.9	2.21	3.42	1.21±0.36	5	96.9	3.62	3.41	0.21±0.83	—	—	—	—	—
97.6–100.0%	3	97.8	0.09	2.54	2.45±0.06	—	—	—	—	—	—	—	—	—	—

TABLE 5.—*Comparison of observed and calculated standard errors for different classes of bunt in spring wheat.*

Bunt classes	Bozeman, Mont., 1933					Pullman, Wash., 1935				
	Number of pairs of rows	Average percentage of bunt	Standard error			Number of pairs of rows	Average percentage of bunt	Standard error		
			Observed	Calculated	Difference			Observed	Calculated	Difference
0.1– 2.5%	94	0.6	0.56	1.72	1.16±0.06	23	0.9	0.95	1.66	0.71±0.12
2.6– 5.0%	6	4.1	1.66	4.37	2.71±0.26	8	3.7	3.42	3.42	0.00±0.62
5.1–10.0%	27	7.8	4.06	5.92	1.86±0.45	12	7.8	4.65	4.83	0.18±0.79
10.1–20.0%	38	15.3	8.13	7.96	0.17±0.70	37	15.4	6.61	6.50	0.11±0.59
20.1–30.0%	53	25.7	9.27	9.66	0.39±0.70	26	25.8	6.97	7.87	0.90±0.77
30.1–40.0%	26	34.2	11.21	10.48	0.73±1.16	34	36.2	10.29	8.65	1.64±0.89
40.1–50.0%	19	45.2	13.56	11.00	2.56±1.60	38	44.7	9.45	8.95	0.50±0.90
50.1–60.0%	10	56.3	17.55	10.96	6.59±2.79	19	55.0	9.01	8.96	0.05±1.10
60.1–70.0%	14	67.0	12.44	10.39	2.05±1.70	13	64.0	10.51	8.64	1.87±1.51
70.1–80.0%	13	74.2	14.69	9.67	5.02±2.06	2	76.3	2.12	7.66	5.54±0.80
80.1–90.0%	8	85.7	4.06	7.74	3.68±0.77	6	86.9	4.37	6.07	1.70±0.90
90.1–95.0%	1	91.5	2.12	6.16	4.04±1.07	29	93.3	3.71	4.51	0.80±0.36
95.1–97.5%	—	—	—	—	—	15	95.9	2.74	3.56	0.82±0.36
97.6–100.0%	—	—	—	—	—	1	98.0	1.91	2.56	0.65±0.97

of these limitations. For the same reason, chi-square, as ordinarily used, is not applicable to the problem considered here. The extent to which heterogeneity (principally soil) affected the data reported

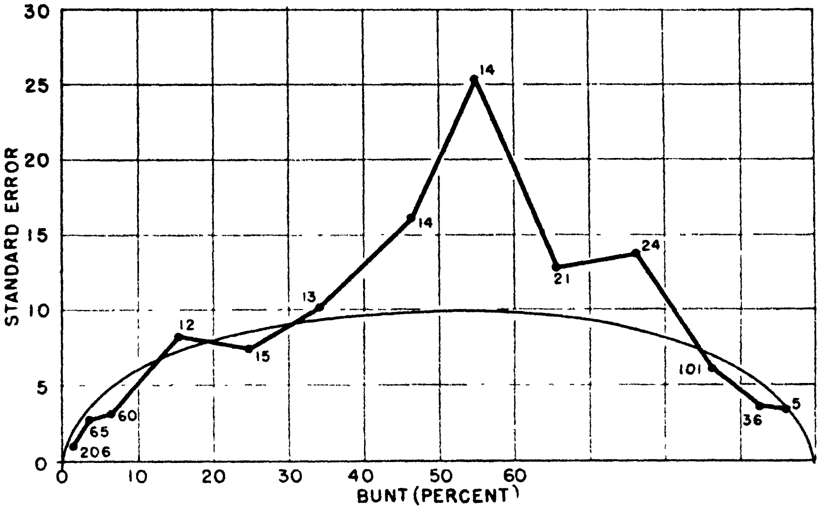

FIG. 1.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for winter wheat at Pullman, Wash., 1935. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form. $\sigma = 3.940\sqrt{\frac{pq}{N}}$. N = 400.

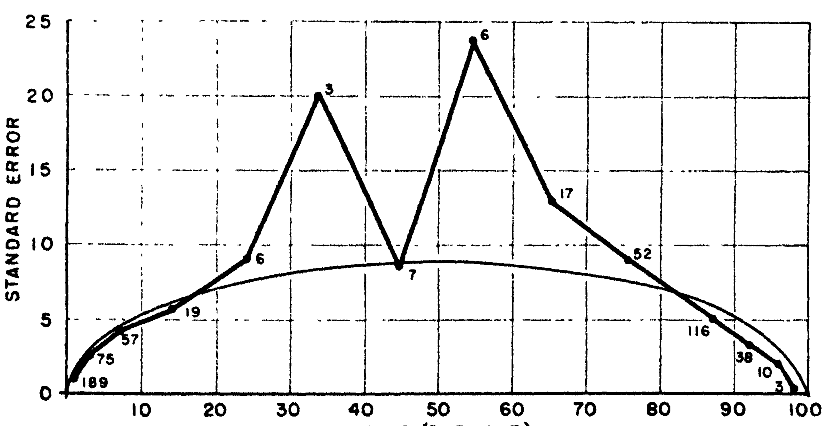

FIG. 2.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for winter wheat at Kearneysville, W. Va., 1935. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 2.432\sqrt{\frac{pq}{N}}$. N = 200.

herein may be realized from the fact that in no one of the five experiments does simple sampling account for more than one-half of the standard error, or one-fourth of the variance due to total random variation. In one case (winter wheat at Pullman, Wash.) it accounts for only one-fourth of the standard error, or one-sixteenth of the variance.

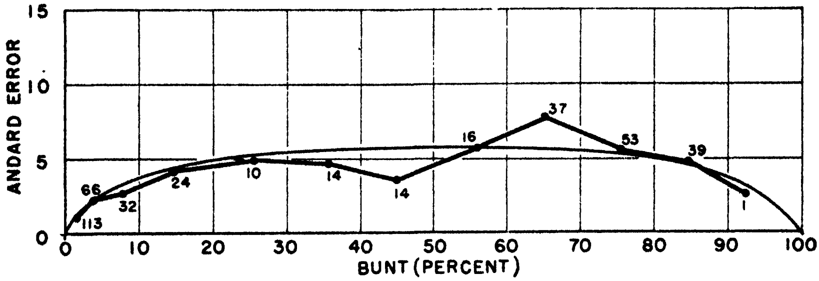

FIG. 3.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for winter wheat at Bozeman, Mont,. 1934. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 2.096\sqrt{\frac{pq}{N}}$ N = 300.

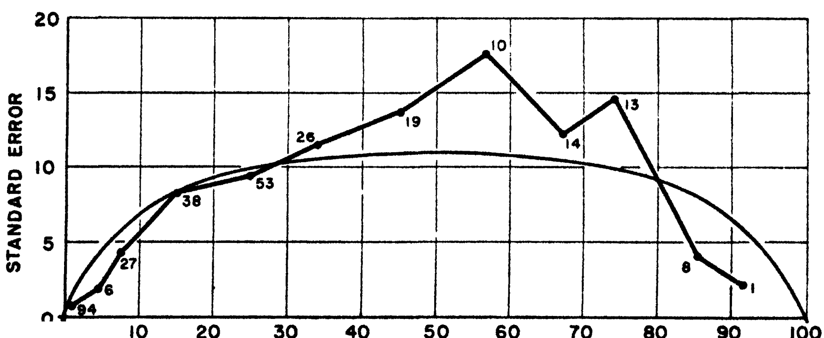

FIG. 4.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for spring wheat at Bozeman, Mont., 1933. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 3.125\sqrt{\frac{pq}{N}}$ N = 200.

Another question relates to the reason or reasons for the departures from the fitted curves as noted above. They are not known with certainty but some of the possibilities seem to merit consideration. The different varieties of wheat are represented very unequally in the different bunt classes (Tables 4 and 5). This, of course, follows from the fact that the varieties differed greatly in their susceptibility to bunt as shown in Tables 2 and 3. Thus, for example, at Kearneysville, the class 0.1 to 2.5% is made up almost entirely of Hohenheimer

and Oro, with a few pairs of rows each from Hussar, White Odessa, Martin, Albit, and Ridit. Neither Minturki, Turkey, nor Hybrid 128 is represented. On the contrary, the classes 70.1 to 80; 80.1 to 90; 90.1 to 95; and 95.1 to 97.4, for spring wheat at Pullman are made up entirely of Ulka. It follows that if there is an inherent tendency for one variety to be more or less variable than another with reference to any collection of bunt, the probability of infection for both varieties being the same, the observed standard errors, as reported in this paper, would be expected to deviate from the theoretical.

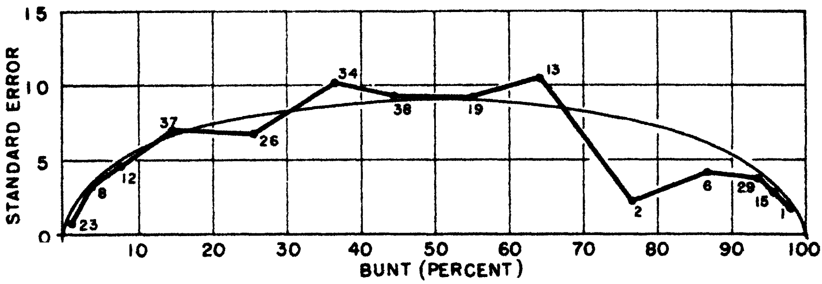

FIG. 5.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for spring wheat at Pullman, Wash., 1935. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 3.600\sqrt{\frac{pq}{N}}$. $N = 400$.

In all cases the percentage of bunt is expressed as a percentage of heads rather than of plants. This means that there is a certain but undetermined degree of correlation in the data which, as Yule points out (11, page 287), affects the standard error. Moreover, the effect probably is not the same for all varieties because of differences in rate of tillering. Heads from late tillers are more likely to be bunted than those from early tillers, and it is possible that the varieties included in the study differed in tiller development. To what extent these various circumstances may have affected the standard errors is not known. An attempt has been made to study them, but the result is far from conclusive because of the difficulty of securing enough comparisons between varieties at the same level of infection. Data bearing on this point are presented in Table 6. This table includes a tabulation of the standard errors for different varieties for the same bunt classes in so far as such data are available, except that no data are included where the number of pairs of rows entering into the calculation is less than 10.

Pairs of varieties in which the difference between their standard errors is approximately as great as or greater than twice the standard error of the difference are tabulated in Table 7.

It will be noted that standard errors of a number of varieties at the same level of bunt infection appear to differ significantly from those of others. However, the differences are in no case very great, the number of cases where there are such differences is rather few,

TABLE 6.—*Comparison of standard errors for different varieties of wheat at similar levels of infection.*

Bunt class and variety	Number of pairs of rows	Average percentage of bunt	Standard error
	Pullman, Wash., Winter Wheat		
0.1–2.5%:			
Albit	20	0.9	0.81±0.13
Oro	27	1.6	1.14±0.16
Ridit	24	1.5	1.11±0.16
Hussar	45	0.8	0.73±0.08
White Odessa	27	0.7	0.74±0.10
Hohenheimer	26	0.8	1.50±0.21
Martin	37	1.0	0.91±0.11
2.6–5.0%:			
Ridit	25	3.8	2.09±0.30
Oro	17	3.8	1.56±0.27
5.1–10.0%:			
Ridit	21	7.2	4.00±0.62
Oro	27	6.7	2.48±0.34
80.1–90%:			
Hybrid 128	36	86.7	6.62±0.78
Turkey	24	86.0	6.79±0.98
Albit	19	85.3	6.11±0.99
White Odessa	15	85.4	4.54±0.83
	Pullman, Wash., Spring Wheat		
40.1–50%:			
Marquis	13	44.8	9.17±1.80
Ruby	19	44.0	10.47±1.70
	Bozeman, Mont., Spring Wheat		
10.1–20.0%:			
Vernal emmer	13	16.2	8.63±1.69
Ruby	14	14.1	6.38±1.21
20.1–30.0%:			
Vernal emmer	18	24.7	10.75±1.79
Mindum	16	26.2	11.00±1.95
Marquis	12	25.7	5.04±1.03
	Kearneysville, W. Va., Winter Wheat		
0.1–2.5%:			
Ridit	18	1.7	1.72±0.29
White Odessa	20	1.1	1.44±0.23
Hohenheimer	17	1.3	1.34±0.23
Oro	31	1.4	1.43±0.18
Albit	25	0.9	—
Martin	35	1.3	—
Hussar	42	1.0	1.00±0.11
70.1–80.0%:			
Turkey	13	74.2	11.98±2.35
Minturki	20	76.1	8.40±1.33
Martin	11	76.8	6.53±1.39
	Bozeman, Mont., Winter Wheat		
0.1–2.5%:			
Oro	23	1.7	1.31±0.19
Ridit	24	1.3	1.30±0.19
Hohenheimer	25	0.9	1.09±0.15

TABLE 7.—*Pairs of varieties in which differences in standard errors appear to be significant or nearly so.*

Variety	Bunt class	Difference in standard errors
Pullman winter wheat:		
Hohenheimer—Hussar	0.1– 2.5%	0.77±0.22
Hohenheimer—White Odessa	0.1– 2.5%	0.76±0.23
Hohenheimer—Albit	0.1 2.5%	0.69±0.25
Oro—Hussar	0.1– 2.5%	0.41±0.18
Oro—White Odessa	0.1– 2.5%	0.40±0.19
Ridit—Oro	5.1–10%	1.52±0.71
Turkey—White Odessa	80.1–90%	2.25±1.28
Bozeman spring wheat:		
Vernal emmer—Marquis	20.1–30%	5.71±2.07
Mindum—Marquis	20.1–30%	5.96±2.21
Kearneysville:		
Ridit—Hussar	0.1– 2.5%	0.72±0.31
Turkey—Martin	70.1–80.0%	5.45±2.73

and as pointed out by Tippett (9, page 54), differences somewhat greater than twice the standard error are necessary as indicative of significance where specific comparisons of two varieties of several possible comparisons are selected for consideration. Altogether it would seem that while the possibility of varietal differences must be considered, it is quite clear that in the present case they are hardly sufficient to account for the difference between the observed and the theoretical curves.

It will be noted that the principal deviations between the observational and theoretical curves occur in the intermediate bunt classes. In fact, if the classes between 30.1 and 70% at Kearneysville, the 50.1 to 60% class for Pullman, and classes between 60.1 and 80% for spring wheat at Bozeman be disregarded for the time being, theoretical curves may be drawn which will fit the remaining classes in a very satisfactory manner.

What appears to be a satisfactory explanation for the discrepancies in the intermediate classes may be arrived at as follows: If experiments such as those under consideration were conducted on a perfectly homogeneous field, it would be expected that the total random error would be accounted for by simple sampling. It therefore seems reasonable to assume that the discrepancies referred to are an expression of the lack of homogeneity of the experimental conditions. Lack of homogeneity would have no effect on the variability of a variety of wheat immune from bunt, since there would be no variation. Its effect would be small on a highly resistant variety. The effect would also be small for any pairs of rows of a very susceptible variety falling into the higher bunt classes; otherwise they would not fall in those classes. No such limitations, however, apply to the intermediate classes. The net result would appear to be standard errors in excess of the theoretical in those classes near and above the 50% level of infection, which agrees with the observations. Whether this is the true explanation cannot be determined with certainty from the available data.

There does not, however, appear to be anything in them to the contrary.

The arbitrary grouping into classes according to the average percentage of bunt in the pairs of rows may possibly have had a slight effect. Such grouping would tend to reduce the standard error for those with a very small or a very high percentage of bunt as compared with what would likely be observed for a large number of rows of a homogeneous variety which had either a very low or a very high percentage of bunt. The effect, however, would be small and it is believed has been a negligible factor in the present study.

The distribution of smutted rows is not always normal and this appears especially likely to be the case for highly resistant or near immune varieties. Whether this has had anything to do with the discrepancies between the observed and theoretical curves is not known. It does have a bearing on the accuracy or reliability of generalized estimates of error.

The results, as a whole, raise a number of questions to which the available data provide no definite answer. One is whether any estimate of random errors sufficiently reliable to be of use can be calculated for experiments such as those under discussion in which the number of replications is very few and in which a generalized standard error calculated from data pooled without reference to infection is not valid.

Grouping the data according to percentage of bunt and calculating separate standard errors for each group, such as was done in the present study, are naturally suggested. The smaller the range for each group and the fewer the varieties or other sources of heterogeneity in each group, the more accurate is the final result likely to be. Curves may be fitted to the observed standard errors, as already described, and these may then be used to estimate the standard error for any level of bunt infection. When the calculated curve fits the observed standard errors reasonably well throughout the entire range of bunt infection, this method should prove satisfactory.

For situations such as those for winter wheat at Kearneysville and Pullman and for spring wheat at Bozeman, it would appear that any standard errors calculated from the theoretical curve will be approximations only. It would be possible, however, to fit curves to portions of the range in which the fit is good, and these may then be used for estimating standard errors within this range. Thus, at Bozeman, a curve fitted for the range from 0 to 35% bunt would be expected to give reliable estimates of standard error within this range. A similar procedure would appear to be satisfactory for the ranges from 0 to 25% and from 85% to 100% bunt at Kearneysville, and for the range 0 to 35% for winter wheat at Pullman. For other portions of the range for these particular experiments any estimates of random error that might be derived by any known method would be highly speculative.

This method of estimating the random error by grouping is of course somewhat empirical since the results depend to some extent on the size of the bunt classes. This involves no precedent, however, and it appears to be much more reliable than those in current use. It would appear that there is abundant justification for using it until a better one is devised.

Collins and Longley (3) have pointed out that the ratio of the standard errors for various levels of infection to the standard error for 50% infection is given by the expression $\sqrt{\frac{50}{pq}}$. Collins[4] has suggested that variances can be equalized by multiplying those for each level of infection by the ratio $\frac{\bar{p}\,\bar{q}}{p\,q}$ where $\bar{p}$ is the average percentage infection, $\bar{q}$ the average not infected, and p and q are the percentage infected and not infected for any given case. The variances may then be averaged to secure a generalized estimate of error. This must then, of course, be multiplied by $\frac{p\,q}{\bar{p}\,\bar{q}}$ to secure the appropriate value applicable to any given degree of infection. This method accomplishes substantially the same result as grouping the data noted above and of course depends for validity on the assumption that the relation between standard error and infection is that of the fitted curve.

Perhaps it is of most importance for the reader to realize that no known method of calculation will always assure a strictly accurate and reliable estimate of standard error from grouped data such as those considered herein. Consequently, such estimates should be considered as rough approximations only until the contrary is proved. If such approximate estimates of random error are considered too inaccurate, it would seem that the only recourse is a more elaborate experiment in which the number of replications is sufficient to afford at least a reasonably reliable measure of random variation for each variable.

Another question of considerable interest and importance is whether the use of generalized standard errors may not lead to erroneous conclusions in experiments other than those involving bunt in wheat. Aamodt and Platt (1), for example, have derived a single error term by analysis of variance for loose smut infection in varieties of oats. Allison (2) has followed a similar procedure for smut in barley and Youden (10) for tobacco mosaic. Data presented by Hoppe and Holbert (6) show very clearly that generalized errors, as usually derived, could not logically be applied to kernel-rot data in corn if the range in infection is very great.

There is also considerable doubt as to whether the use of generalized standard errors for yield and other quantitative data may always be justified. Data suitable for critical studies of these relations are very meager or do not exist, but enough has been accumulated to convince the writer that caution is necessary if serious errors are to be avoided. It appears that significant differences between the variances of different varieties of small grain, for example, are especially likely to be found when some varieties yield near 0 and others produce moderate or high yields. The variance for yield of roots of certain perennial weeds has been found, in general, to be materially less on continuously cultivated plats, where the yield is low, than on uncultivated plats when the yield is high. Other examples might be cited.

[4]Orally.

Certainly, as previously mentioned, the practice sometimes followed and recommended of including data from different stations and different seasons in a single analysis of variance set-up and in which a single error term is applied to all stations and seasons alike cannot be justified as a general procedure, though it may not lead to erroneous conclusions in particular cases. Instances in which it can be shown that significant differences in variance occur within a single experiment for one season at one place apparently are not common, and hence it should not be inferred that generalized standard errors are never valid or useful. The point it is intended to emphasize is that caution is essential and that the possibility of significant differences should always be considered.

SUMMARY

Data are presented from tests to determine differences in bunt infection in wheat varieties which show that estimating random variation by analysis of variance, or by any method in which all varieties are grouped together irrespective of bunt infection, may be seriously in error when varieties are included which differ materially in infection. The binomial and chi-square determinations, as generally used for estimating statistically significant differences, also are unreliable for bunt resistance tests, for the reason they take into account only the random variation due to simple sampling and not that due to heterogeneity in environment (principally soil differences).

The data suggest that estimates of random error commonly employed in similar experiments dealing with other diseases of plants, or with certain variables other than plant diseases, also may be in error.

In bunt tests with wheat it was found, as would be expected, that the standard error is to a considerable degree a function of the infection, approaching 0 at 0 and 100% infection and reaching a maximum at or near the 50% level of infection. The form of the curve is similar to that expressed by the binomial. Introducing a constant into the binomial formula to account for random errors other than those due to simple sampling makes it possible to predict the standard errors with a fair degree of accuracy when the observed standard error for any given level of infection is known.

A method of estimating standard errors for grouped bunt data is suggested, making use of the relation between standard error and bunt infection. This method is not regarded as strictly accurate since it assumes like standard errors for all varieties at the same level of infection. It is not known that this assumption is always realized in practice; however, the method is believed to be more reliable than those generally employed.

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SELENIUM AND TENMARQ WHEAT[1]

Alfred T. Perkins and H. H. King[2]

CONSIDERABLE interest has recently been aroused in the toxicity of selenium to plant and animal life. The work of the U. S. Dept. of Agriculture has been outstanding in this regard. Selenium has been found in parts of Kansas, and the data reported here have been collected as a result of general interest in selenium and elements of minor importance to plant growth. The initial objective in this problem was to determine the toxicity of selenium to Tenmarq wheat grown in Derby soil in the greenhouse. Tenmarq is a winter wheat having many desirable characteristics.

Glazed porcelain pots of 2-quart capacity were filled with 1,750 grams of well-mixed Derby soil and treated with various amounts of selenium added as $Na_2SeO_4.10H_2O$. The amount of selenium added varied from 0 to 100.00 p. p. m. of dry soil. The exact applications are outlined in Table 1.

Table 1.—*Chloratic conditions and germination of Tenmarq wheat as affected by various selenium applications, wheat sown October 3, 1935.*

Pot No.	Selenium added, p.p.m.	Ave. No. sprouts per pot on Oct. 5	Ave. No. sprouts per pot on Oct. 8	Selenium injury on Oct. 14
1-2	0.0000	Not seeded	Not seeded	No wheat
3-11	0.0000	5	10-	None
12-20	0.4096	7	10-	None noticeable
21-29	1.0240	7	10-	A little chlorosis at base of some primary leaves
30-38	2.5600	7	10	Chlorosis and slight rose coloration from base of primary leaves and yellow color at leaf tips
39-47	6.4000	5	10-	As above
48-56	16.0000	5	8	Some chlorosis, considerable leaf yellowing, and gummy exudate on leaf tips
57-64	40.0000	2	4	Scant growth and as above
65-72	100.0000	1	1	No growth

Nine pots were prepared for each selenium application as well as nine pots with no selenium and two unplanted check pots with no selenium. Twelve seeds were planted in each pot on October 3, 1935, and growth started by adding 300 cc. of water to each pot. Three times a week the pots were weighed and sufficient water added to restore them to their original weight.

Germination, early chlorotic conditions, and other data are given in Table 1. From the data in Table 1 it seems that small amounts of selenium somewhat encourage early germination as on October 5 only an average of five seeds each had germinated in pots receiving

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no selenium, while in pots receiving the lighter applications of selenium an average of seven seeds each had germinated. Heavier selenium applications, however, caused a decrease in germination. On October 8, 0 and slight selenium applications showed the same degree of germination as applications up to and including 6.4 p.p.m.

The data recorded in Tables 2 and 3 give an indication of the plant growth by giving the height of the seedlings and mature plants, the amount of water consumed per pot above that consumed by the blank pots (Nos. 1 and 2), and the harvest weight of the wheat. It appears that early growth of the wheat was aided by a light application of selenium. Germination was encouraged and the height of the week-old plants grown in soil with 0.4096 p.p.m. of selenium was slightly greater than that of the plants grown in selenium-free soil. It is apparent, however, that the early physiological activity of the plants was decreased by applications of selenium. Up until February the water consumed by the plants was inversely related to the amount of selenium applied. At this stage of growth, when the wheat would normally be in the winter rest stage, the general appearance of the wheat, height of plants, etc., varied indirectly as the amount of selenium applied.

TABLE 2.—*Height of wheat plants and dry weight at maturity as affected by applications of selenium, wheat sown October 3, 1935.*

Pot No.	Selenium application, p.p.m.	Height of wheat in inches		Dry weight at harvest, grams	Mature seeds found
		Oct. 15, 1935	May 2, 1936		
1-2	0	Blank	Blank	Blank	Blank
3-11	0	5½	12	15	Yes
12-20	0.4096	5¾	17	18	Yes
21-29	1.0240	5¼	20	30	Yes
30-38	2.5600	4½	19	23	Yes
39-47	6.4000	4¼	*	*	No
48-56	16.0000	3	*	*	No
57-64	40.0000	1¼	*	*	No
65-72	100.0000	¼	*	*	No

*No growth with this and increasing treatments

The check pots with no selenium appeared the best, and growth decreased as the amount of selenium applied increased. The pots of wheat were kept in the greenhouse all winter, and the wheat was not permitted to go into the full dormant stage. As the activity of the plants increased in February, the growth of the wheat seemed to reverse itself; the pots receiving selenium applications began consuming significantly more water and growing faster. A photograph (Fig. 1) taken on March 3, 1936, shows how selenium stimulated the spring growth of Tenmarq wheat. Pot No. 1 received no selenium; No. 2, 0.4096 p.p.m.; No. 3, 1.0240 p.p.m.; and No. 4, 2.5600 p.p.m. All heavier selenium treatments killed the wheat. The final harvest weights of the wheat indicate that the best growth was obtained when the soil was treated with 1 p.p.m. of selenium. The increased growth of wheat resulting from small applications of selenium checks with the

TABLE 3.—*Water consumption as affected by applications of selenium, wheat sown October 3, 1935.*

Pot No.	Water in cc lost during 2-day periods ending									Total amount of water lost, cc
	Oct. 15, '35	Oct. 26, '35	Nov. 23, '35	Dec. 21, '35	Jan. 23, '36	Feb. 24, '36	Mar. 19, '36	Apr. 21, '36	May 2, '36	
1–2	Blank	Blank	Blank	Blank	Blank	Blank	Blank	Blank	Blank	Blank
3–11	11	24	24	35	6	17	35	35	7	1,522
12–20	11	24	20	37	4	27	50	40	14	2,003
21–29	10	18	16	31	2	37	70	65	16	2,274
30–38	6	15	10	10	0	21	65	70	12	1,661
39–47	7	11	4	3	Dead	Dead	Dead	Dead	Dead	231
48–56	6	10	3	Dead	Dead	Dead	Dead	Dead	Dead	118
57–64	3	Dead	Dead	Dead	Dead	Dead	Dead	Dead	Dead	60
65–72	0	Dead	Dead	Dead	Dead	Dead	Dead	Dead	Dead	23

EXPERIMENTAL RESULTS

The results of different replications were in general very consistent. The readings of duplicate or quadruplicate pots of like treatment varied in only a few cases more than two and three points on the seedling reading scale, while most of the readings were practically identical. Readings on the sod material were even more uniform with no greater discrepancy than two points. The mean readings of drought injury for the three types of growth stages are given in Table 1.

TABLE 1.—*Mean comparative injury of 30-day seedlings, 60-day seedlings, and sod plants in readings of 0–10 scale for seedlings and 0–6 for sods, after drought treatment of 10, 16, 20 and 26 hours duration. (0 = complete death in each growth stage group).*

Pot No.	Forage crop	Treatment in hours for growth stage groups*								
		30-day seedlings			60-day seedlings			Sod material		
		10†	16	20	10	16	20	16	20	26†
1	Timothy, commercial	3.8	0.0	0.0	8.5	7.5	0.0	4.0	3.5	1.7
2	Crested wheat grass, forage	9.0	9.0	2.5	9.0	7.0	5.5	5.5	4.0	2.5
3	Timothy, pasture type	2.8	0.0	0.0	7.5	6.5	0.0	4.0	2.0	0.5
4	Brome grass, commercial	9.0	7.0	4.0	9.0	8.0	8.0	6.0	5.0	3.8
6	Crested wheat grass, Fairway	8.0	7.0	0.0	7.0	6.0	2.0	6.0	3.0	0.8
7	Brome grass, non-creeping	8.5	4.0	0.0	9.0	9.0	4.0	5.5	4.0	3.0
9	Reed canary grass	—	—	—	—	—	—	4.0	3.0	1.0
10	Meadow fescue	8.0	4.0	0.5	9.0	8.0	4.5	3.5	1.0	0.0
11	Canada bluegrass	3.8	0.0	0.0	8.5	6.5	1.5	5.5	3.0	1.0
13	Meadow foxtail	3.8	1.5	0.0	8.5	7.0	4.5	4.5	3.0	1.0
14	Kentucky bluegrass	3.2	0.0	0.0	8.0	7.0	1.0	5.0	2.5	1.0
15	Slender wheat grass	—	—	—	—	—	—	5.0	5.5	3.0
17	Chewings fescue	6.2	1.5	0.0	8.0	6.0	0.5	5.5	1.5	0.2
19	Creeping fescue	7.2	3.5	0.0	9.0	9.0	0.5	4.5	2.5	0.2
21	Brown top	—	—	—	—	—	—	2.0	0.5	1.2
22	Orchard grass, commercial	5.5	1.5	0.0	8.5	6.0	1.0	5.0	2.5	1.5
23	Red top	2.2	0.0	0.0	8.0	4.0	0.5	3.0	0.0	0.2
36	Alsike clover	4.2	0.5	0.0	7.0	4.0	0.0	5.5	2.0	0.5
41	Alfalfa, Grimm	8.5	3.5	0.0	9.0	7.5	4.0	5.0	4.5	1.2
46	Wh. Bl. sweet clover	8.0	0.0	0.0	8.5	4.0	0.0	—	—	—
51	Medium red clover	2.0	0.0	0.0	6.0	2.0	0.0	—	—	—
62	White clover	1.8	0.0	0.0	6.0	2.0	0.0	—	—	—

*0 = Complete death in each growth stage group.
†Average of 4 replications, whereas the other treatment periods are averages of 2 replications.

For the 30-day old seedlings the 20-hour drought exposure was lethal to all varieties of grasses and legumes tested except forage crested wheat grass, commercial brome grass, and meadow fescue. One of the two pots of meadow fescue received a score of 1 by having some survival. The brome grass had about a one-third to one-half survival, while the crested wheat grass showed about 25% survival.

The 16-hour treatment for this growth stage gave much less severe injury. Forage crested wheat grass with a scale reading of 9 had tip injury of the leaves. Commercial brome grass and the Fairway strain of crested wheat grass showed severe foliage injury and a small per-

centage of seedlings that were killed. Non-creeping brome grass, meadow fescue, creeping fescue, and Grimm alfalfa all survived 20 to 50%. Other forages were very severely injured or entirely killed.

The 10-hour treatment gave less injury than longer treatments and all forages had some survival. Commercial and pasture type timothy, Canada and Kentucky bluegrass, meadow foxtail, red top, and medium red and white clover were injured most severely. The two strains of timothy and the two strains of brome grass in this growth group are shown in Fig. 1 after 10 hours and 16 hours treatments together with their checks.

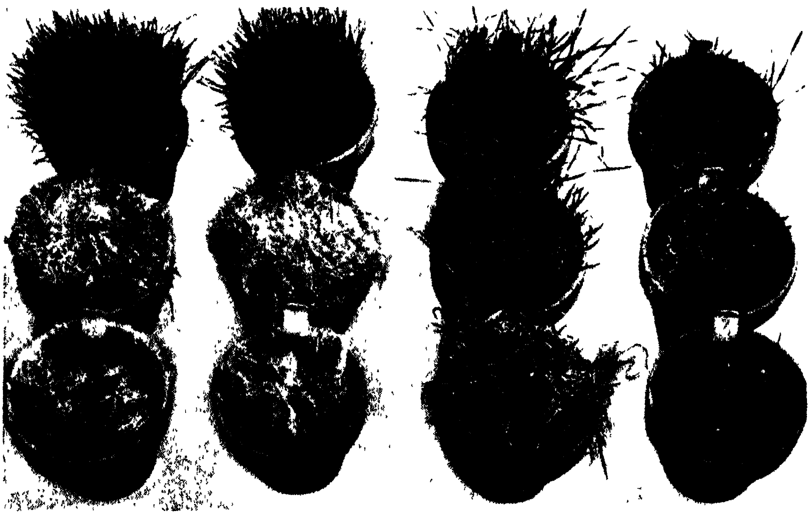

FIG. 1—Comparative injury by artificial drought on two strains of timothy and two strains of brome grass in 30-day-old seedlings. The three-pot rows from left to right are commercial timothy, pasture type timothy, commercial brome grass, and non-creeping brome grass. The front row of pots was exposed to drought for 16 hours, the second row for 10 hours, and the back row are the untreated checks. The photo was taken two weeks after the drought treatment.

The comparative injury to the 60-day growth stage group was similar to that of the 30-day-old seedlings except that injury was less severe. For the 20-hour exposure, commercial and non-creeping brome grass, forage crested wheat grass, meadow fescue, meadow foxtail, and Grimm alfalfa had 50% or better of survival. Meadow foxtail was much more drought resistant in the 60-day seedling stage than in the 30-day seedling stage. With 16 hours of exposure all forages withstood the drought test relatively well, except for white and red clover which showed only about 20% survival. The 10-hour exposure was much less injurious than the longer exposures, with red and white clover showing most severe injury.

More severe treatments were necessary for a good differential in the sod materials. Slowness of recovery from injury rather than complete death was usually common in this group. The averages for the 26-

hour exposure in Table 1 comprise a mean of four replications. The hardier types of grasses were forage crested wheat grass, commercial and non-creeping brome grass, and slender wheat grass. Other forages with somewhat less than fair recovery according to the scale used were commercial timothy, Fairway crested wheat grass, reed canary grass, Canada and Kentucky bluegrass, meadow foxtail, brown top, orchard grass, and Grimm alfalfa.

While it is not possible to compare directly the sod growth stage readings and those of the seedlings, there is rather consistent agreement between all three stages. In comparing the two seedling groups it is noticeable that with comparable treatments the older seedlings possessed considerably more resistance to these drought conditions than did the 30-day-old plants.

During the last two years these same forages have been grown in single plots without replication at the central station in St. Paul and at the branch stations at Waseca, Morris, Grand Rapids, and Duluth. One end of each plot was cut with a lawn mower whenever the plants reached approximately 4 inches in height and the other end of the plot was harvested at the proper hay stage. A further year's study of these plots will be made before the data are studied in detail and survival determined in relation to botanical composition.

Drought conditions were most severe at University Farm and Morris. Stands of brome grass and crested wheat grass were successful when other forages were injured by drought. Alfalfa, while not as resistant as these two grasses, resisted drought better than sweet clover. Other clovers were killed completely. Varieties of grasses or legumes that best withstood drought injury under field conditions were most resistant also when tested under artificial drought conditions either in the 30- or 60-day-old seedling stages or in the sod stage of growth.

SUMMARY

A series of forage grasses and legumes, which have been grown under field trials at the central and branch stations in Minnesota in the past two years, were tested for drought resistance in an artificial drought machine. There was very good agreement of results of these artificial drought trials with those obtained under field conditions. In both tests, crested wheat grass and brome grass proved most drought resistant, while among the legumes, alfalfa was most drought resistant. Artificial tests of drought resistance may be used therefore to indicate those species or varieties of forages which can be expected to succeed best under natural drought conditions.

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EFFECT OF FERTILIZATION, CUTTING TREATMENTS, AND IRRIGATION ON YIELD OF FORAGE AND CHEMICAL COMPOSITION OF THE RHIZOMES OF KENTUCKY BLUEGRASS (*Poa pratensis* L.)[1]

H. L. AHLGREN[2]

IT has long been known that the pasture complex is the resultant of the interplay of climatic, soil, and biotic factors; the latter including pasture management. Numerous investigations made under varying soil and climatic conditions have provided considerable information relative to the improvement of grassland by the use of commercial fertilizers. In general, the data which have been accumulated indicate that marked responses may be obtained by the use of commercial fertilizers on soils which are deficient in fertility (1, 2, 3, 4, 5, 6, 12, 15).[3]

Most studies relative to the management of pasture grasses and legumes which have been described in the literature were designed to compare yields of forage obtained under a system of frequent defoliations with that of a hay stage of growth. Conclusive evidence is available to indicate that forage cut or grazed closely and frequently is injured and yields are reduced (7, 8, 9, 10, 11, 13, 14, 16, 18). It has also been shown that different species react differently to different intensities of grazing. Graber, *et al.* (10), found that where 22 close cuttings with a lawn mower did not kill Kentucky bluegrass, only 9 cuttings of alfalfa resulted in death to nearly all plants. Carrier and Oakley (5) and Wiggans (17) have reported that Kentucky bluegrass yields approximately as much when cut frequently as when cut for hay.

The objectives of the study reported in this paper were (a) to determine the effect of different intensities of clipping on the yield of Kentucky bluegrass, (b) to study the response of Kentucky bluegrass to complete fertilization and irrigation, and (c) to determine the effect of the different clipping and fertilization treatments on the carbohydrate reserve of the rhizomes.

PLAN OF EXPERIMENT

The experiment reported herein was begun in 1931 and concluded in the fall of 1936. It was located on the West Hill University Farm at Madison, Wisconsin, on an old bluegrass sod. The soil on which the studies were made is a Miami silt loam varying in pH from 5.8 to 6.3. The plats were 1/200 acre in size each separated by a 2-foot alley. All of the fertilizer and cutting treatments were replicated four times.

[1]Part of a thesis submitted at the University of Wisconsin in partial fulfillment of requirements for the degree of doctor of philosophy. Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication April 30, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 690.

Three different cutting variables were employed in the experiment. The first cutting variable was intended to approximate normal controlled grazing. The grass was permitted to grow to a 4- to 5-inch height and then cut, leaving a stubble of 1½ inches. The second type of cutting management was designed to imitate the effect produced under a system where grazing is deferred in the spring. The grass was cut in the early heading stage, just as the panicles were emerging from the sheaths, leaving a stubble of 1½ inches. The aftermath produced thereafter was removed whenever it reached a height of 4 to 5 inches. The third cutting variable was included to study the comparative effect of permitting the grass to make an uninterrupted growth to a late heading stage before harvesting. The hay was cut down to a 1½-inch level and the aftermath removed regularly when 4 to 5 inches high.

One-half of the plats in each cutting series were fertilized at the acre rate of 200 pounds of muriate of potash, 400 pounds of 20% superphosphate, and 400 pounds of ammonium sulfate. The remaining plats were not fertilized. The nitrogen fertilizer was applied each year in a single application in the early spring. The mineral fertilizers were applied only in 1932. Cutting was done with a lawn mower equipped with a grass catcher except on the plats permitted to grow to a late hay stage where a scythe was used. Preliminary cutting studies on the area in 1931 prior to the time the fertilizers were applied indicated a marked uniformity in yield from all plats.

Because of unusual early season drought conditions prevailing in 1934, one series of the replicated plats was removed from the regular experiment and irrigated at the rate of 1½ inches of rainfall per week. The purpose of this study was to compare the yield of forage obtained under favorable and unfavorable moisture conditions. The yield of forage produced by each of the irrigated plats was calculated.

Beginning on June 27 and at 3-week intervals thereafter, representative duplicate sods were removed from each of the irrigated plats. The sod samples were removed a week after a cutting was made. The sods thus obtained were washed free of soil and the rhizomes collected. The rhizomes removed from each sod were placed in paper bags and dried at room temperature until early winter, when they were oven dried at 80° C, ground to pass an 80-mesh sieve, and analyzed for carbohydrate content. The method used for analyzing the rhizomes is that described in the third edition of the Official and Tentative Methods of Analysis of the Association of Agricultural Chemists.

RESULTS

EFFECT OF DIFFERENT INTENSITIES OF CLIPPING ON YIELD OF KENTUCKY BLUEGRASS

The detailed data with respect to yield as affected by the cutting treatments used is given in Tables 1 to 4, inclusive. Fisher's analysis of variance was used in evaluating the significance of the differences in yield which were obtained. The minimum difference required for significance at the 5% point between cutting treatments for each fertilizer level was found to be 474.8 pounds per acre. When this value is used as a test of significance, the yield of forage produced in 1932 by the fertilized plats cut as the heads were appearing was significantly higher than that obtained from either the plats cut when 4 to 5 inches high or when fully headed. The yield of forage produced by the fer-

tilized plats cut when 4 to 5 inches high was significantly lower than that obtained from the plats cut as heads were appearing or when fully headed. Differences were not great enough to be of any significance on the unfertilized plats, but the trend was in the same direction. In 1933 the unfertilized plats which were not cut until fully headed were significantly higher in productivity than those cut when 4 to 5 inches high or as heads were appearing. There were no other significant differences in yield due to cutting treatment in 1933, 1934, 1935, or 1936.

TABLE 1.—*The effect of various cutting treatments and fertilization on the yield of Kentucky bluegrass when given complete fertilization.**

Year	Calculated acre yield of dry matter (pounds) at various stages of growth					
	4–5 inches		Early heading		Fully headed to mature	
	Not fertilized	Fertilized	Not fertilized	Fertilized	Not fertilized	Fertilized
1932	1,619	3,113	2,081	4,769	2,050	3,957
1933	2,153	4,295	2,341	4,439	2,977	4,579
1934	1,817	2,114	1,742	2,319	1,681	2,046
1935	1,520	1,932	1,418	1,932	1,279	1,785
1936	826	1,703	595	1,617	435	1,617
Average	1,587	2,631	1,635	3,015	1,684	2,797

*Minimum significant difference in pounds of dry matter between means at 5% level:
Years—193.8
Fertilizers—122.6.
Years × Cuttings × Fertilizers—474 8.

TABLE 2.—*Analysis of variance of data presented in Table 1.*

Item	D.F.	Variance	F value	5%	1%
Years	4–	16378432.57	193.77	2.56	3.72
Cutting treatment	2–	355564.98	4.21	3.18	5.06
Fertilizers	1–	31256491.21	369.79	4.03	7.17
Years × cutting treatments	8–	507228.69	6.00	2.13	2.88
Years × fertilizer treatments	4–	2721138.41	32.19	2.56	3.72
Years × replicates	10–	123805.62	1.46	2.02	2.70
Cutting treatments × fertilizer treatments	2–	241075.20	2.85	3.18	5.06
Years × cutting treatments × fertilizer treatments	8–	129330.32	1.53	2.13	2.88
Error	52	—	—	—	—
Total	91	—	—	—	—

That there was a definite trend in productivity favoring the 4- to 5-inch cutting level on both the fertilized and unfertilized series, even though not significant in any given year, is evident from a review of the data given in Table 4. If the annual productivity of the plats cut when fully headed is taken as 100, the relative yield of forage produced by the fertilized plats cut when 4 to 5 inches high was 79, 92, 113, 108.2, and 143.6 during the period 1932 to 1936, respectively. Likewise, the relative yield of forage produced by the unfertilized plats cut

TABLE 3.—*The effect of various cutting treatments on the yield of irrigated Kentucky bluegrass, 1934.*

Calculated acre yield of dry matter (pounds) at various stages of growth					
Complete fertilization			No fertilization		
4–5 inches	Early heading	Fully headed to mature	4–5 inches	Early heading	Fully headed to mature
5,231	4,631	4,719	2,795	2,438	2,292

TABLE 4.—*Percentage yield of Kentucky bluegrass from various cutting and fertilization treatments for 1932–36, inclusive, when compared to the plats cut at maturity and using 100 as an index of their yield.*

Year	Complete fertilization			No fertilization		
	4–5 inches	Early heading	Fully headed to mature	4–5 inches	Early heading	Fully headed to mature
1932	79	123	100	71	93	100
1933	92	97	100	74	81	100
1934	113	103	100	108	101	100
1934*	111	98	100	122	106	100
1935	108.2	108.2	100	118.8	110.8	100
1936	143.6	105.4	100	189.8	136.7	100

*Irrigated

when 4 to 5 inches high was 71, 74, 108, 118.8, and 189.8 during the period 1932 to 1936, respectively. The same general trend found in the series cut when 4 to 5 inches high is evident on both the fertilized and unfertilized plats cut as heads were appearing although it is not as pronounced.

While these transition differences have not been great enough to show significance in any one year, they do indicate a definite trend in the direction favoring the 4- to 5-inch cutting procedure. It is believed that the relative decreased productivity of the plats on which cutting was deferred until the bluegrass was fully headed may have been due in part to the natural thinning of the turf which resulted from this type of management and the noticeably slower growth recovery from cutting.

RESPONSE OF KENTUCKY BLUEGRASS TO FERTILIZATION AND IRRIGATION

The data given in Tables 1 and 2 indicate that increases in productivity due to fertilization were highly significant in all cases in spite of the unusual drought conditions which prevailed during four of the five years the experiment was in progress. The application of complete fertilization to unirrigated plats increased the average acre yield of dry matter during the 5-year period 1,113 pounds, or 66.1%, on the plats cut when the bluegrass was fully headed; 1,380 pounds, or 84.4% on those cut when seed heads were just appearing; and 1,044 pounds, or 65.8%, on plats cut periodically when 4 to 5 inches high.

The average annual acre increase in yield due to fertilization for all cutting treatments was 1,179 pounds, or 72.1%.

That lack of sufficient moisture may effectively reduce the productivity of Kentucky bluegrass is evident from the data given in Tables 1 and 3. During 1934, one series of the cutting treatments was irrigated in order to eliminate moisture as a limiting factor of growth. Under irrigation, complete fertilization increased the acre yield of dry matter 2,427 pounds, or 105.8%, on the plats cut when the bluegrass was fully headed; 2,193 pounds, or 89.9%, on those cut when the seed heads were just appearing; and 2,436 pounds, or 86.8%, on plats cut when the grass was 4 to 5 inches high. The average increase in yield due to fertilization on the irrigated plats for all cutting treatments was 2,352 pounds, or 94.2%

The average calculated acre increase in yield of dry matter as a result of irrigation on all of the fertilized plats regardless of cutting treatment was 2,700 pounds, whereas the increase as a result of irrigation on corresponding unfertilized plats was 761 pounds. Irrigation increased the average yield 125% on the fertilized plats and 43.6% on the unfertilized plats. A lower increase in yield due to irrigation was obtained from the unfertilized plats than from those which had been fertilized because the fertility necessary for maximum growth was lacking. The data indicate conclusively that moisture and fertilization were both highly significant in increasing production for all of the cutting treatments.

The data given in this paper show that with the exception of 1933, there was a progressive and significant decrease in the yield of bluegrass on all plats, regardless of the cutting or fertilizer treatment used, during the period 1932 to 1936, inclusive There is no indication in the data that the fertilizer or cutting treatments used affected the rate of decrease. The average acre yield of dry matter produced by all of the fertilized plats decreased from 3,947 pounds in 1932 to 1,647 pounds in 1936. During the same period, the average acre yield of dry matter produced by the unfertilized plats decreased from 1,917 to 619 pounds. No reason can be cited to account for these decreases. Unfavorable seasonal conditions may have resulted in thinning of the turf thereby decreasing the yield. The grazing animal is known to have a beneficial effect on the sward, although the exact nature of the benefit derived is not fully understood.

Since much of the information available relative to the improvement of permanent pastures has been based on results obtained from the "lawn mower" type of experiment, it would appear highly desirable to run correlation studies on yield obtained under grazing and clipping treatments.

EFFECT OF DIFFERENT CLIPPING AND FERTILIZER TREATMENTS ON CARBOHYDRATE RESERVE OF THE RHIZOMES

During 1934 representative duplicate square foot sods were removed at 3-week intervals from each of the variously fertilized and clipped irrigated plats. The sods were washed free of soil and the rhizomes removed. Sampling was begun June 27. The rhizomes which

were collected from the variously treated plats were analyzed for their carbohydrate content. The results of this analysis are given in Table 5 and in Figs. 1 and 2. From a review of the data it is evident that the carbohydrate content of the rhizomes of Kentucky bluegrass was higher on the unfertilized plats than on the fertilized plats regardless of the cutting treatment used. This is to be expected since the more rapid growth which results from the use of commercial fertilizers, especially nitrogen, does not lead to an accumulation of large supplies of organic reserves in rhizomes.

TABLE 5.—*Percentage starch equivalent in the rhizomes of Kentucky bluegrass when cut at different stages of growth, 1934.*

Date	Complete fertilization			No fertilization		
	4-5 inches	Early heading	Fully headed to mature	4-5 inches	Early heading	Fully headed to mature
June 27	11.45	17.78	17.35	16.56	18.00	18.65
July 17	16.56	14.00	13.21	18.32	14.05	14.00
Aug. 8	16.70	15.12	13.21	21.24	15.44	14.00
Aug. 27	19.62	19.15	17.78	26.03	21.60	20.45
Oct. 19	23.72	21.10	20.20	26.86	22.07	21.92
Nov. 8	27.04	27.04	27.04	27.18	29.02	28.19

The carbohydrate content of the rhizomes of Kentucky bluegrass cut when 4 to 5 inches high increased progressively from the first date of sampling to the end of the growing period. Apparently a system of management which permits of a return growth of 4 to 5 inches does not lead to a depletion of organic reserves.

Deferring cutting until the early or late heading stages increased the carbohydrate content of the rhizomes at both fertility levels. However, there was a significant decrease in the carbohydrate reserve of the rhizomes under the deferred cutting conditions immediately after the first cutting. Fewer green leaves remained after cutting than on the areas cut regularly when 4 to 5 inches high because of the shading and crowding effect which obviously results from a system of management of this type. Consequently, after the taller top growth was removed, new growth was initiated more completely at the expense of previously stored reserves. With the return of an adequate leaf surface the carbohydrate content increased progressively during the remainder of the growing period.

The data would appear to indicate that none of the systems of management used under the conditions of this experiment would lead to a depletion of organic reserves.

SUMMARY

Results of a field study with Kentucky bluegrass conducted at Madison, Wis., during the period 1932 to 1936, inclusive, are presented. The purpose of the study was to determine (a) the effect of different intensities of clipping on the yield, (b) the response to fer-

tilization and irrigation, and (c) the effect of different cutting and fertilizer treatments on the carbohydrate content of the rhizomes. The data were analyzed according to Fisher's analysis of variance.

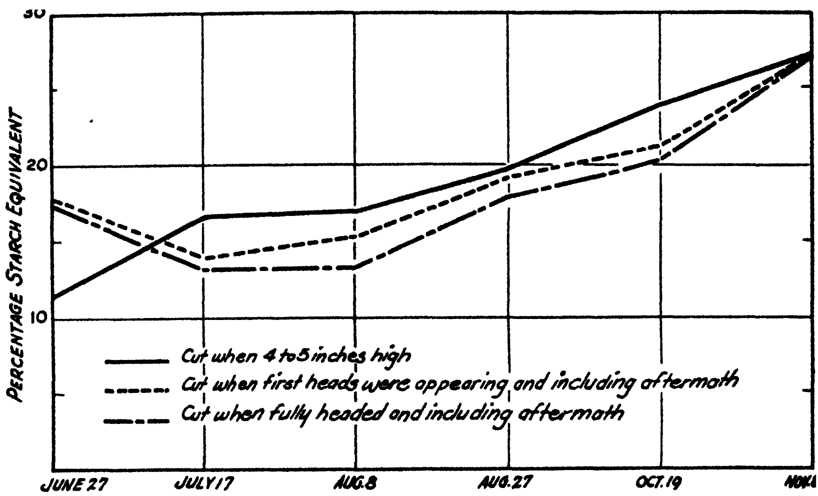

FIG. 1.—Percentage starch equivalent in the rhizomes of Kentucky bluegrass when cut at different stages of growth and receiving complete fertilization.

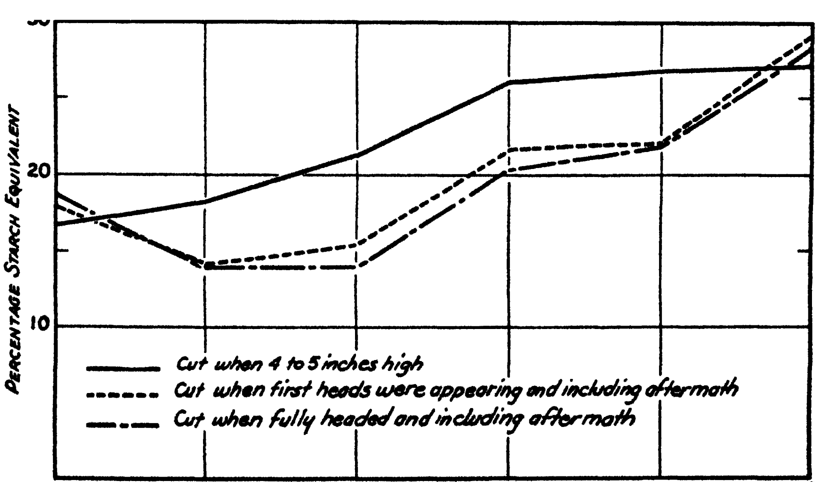

FIG. 2.—Percentage starch equivalent in the rhizomes of Kentucky bluegrass when cut at different stages of growth and not fertilized.

Differences in yield resulting from three cutting variables used were not significant except during the first year of the experiment. However, as the experiment progressed, there was a definite trend in productivity favoring the 4- to 5-inch cutting level on both the fer-

tilized and unfertilized plats even though yearly differences were not significant.

The application of phosphate and potash in 1932 and nitrogen annually, increased the average yield of dry matter 1,179 pounds, or 72.1%, during the 5-year period on the plats which were not irrigated. In 1934 the fertilized plats which were irrigated produced 94.1% more forage than the irrigated unfertilized plats.

During 1934 the fertilized plats which were irrigated at weekly intervals produced 125% more forage than the fertilized plats which were not irrigated. The irrigated plats which were not fertilized produced 43.6% more forage than the unfertilized plats which were not irrigated.

Under the conditions of this experiment, moisture, fertilization, and cutting treatments were effective in the order given in determining the productivity of Kentucky bluegrass. There were no significant interactions between fertilizer and cutting treatments.

There was a significant and progressive decrease in yield for all fertilizer and cutting treatments due to cutting during the period 1932 to 1936, inclusive.

The carbohydrate content of the rhizomes was not appreciably reduced by any of the fertilizer or cutting treatments used on the irrigated plats during 1934.

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A COMPARISON OF MITSCHERLICH TRIALS ON HAWAIIAN SOILS IN GERMANY AND IN THE TERRITORY OF HAWAII[1]

O. C. MAGISTAD[2]

THE use of the Mitscherlich pot culture method (4)[3] for detecting soil deficiencies has become commonplace throughout parts of Europe. Its use outside of Europe has been little investigated. With a view towards possible use of this method for diagnosing pineapple soils in the territory of Hawaii, soil samples were obtained in 1930 from seven field experiments. Mitscherlich pot culture tests were conducted on these soils in Germany, and later in Hawaii, and this paper reports and compares the results obtained.

EXPERIMENTAL PROCEDURE

PREPARATION AND DESCRIPTION OF SOILS

The soils used were collected by taking a uniform section to the depth of about 12 inches at regular, frequent intervals throughout the experimental area. The entire sample of about 500 pounds from a single field was thoroughly mixed for several hours in a large clean cement mixer. Approximately one-half was shipped in barrels to E. A. Mitscherlich in Konigsberg, East Prussia, Germany. The remainder was stored in Honolulu for later tests.

The seven soils used are described in Table 1 together with some of their characteristics.

The percentage of colloids as shown in Table 1 was determined using the method of Bouyoucos (2) with temperature corrections as indicated by Richter (6).

TABLE 1.—*Description of soils used.*

Soil No.	Experiment No.	Island	Colloid %	pH	Readily available	
					P, p.p.m.	K_2O, M.E./100 grams
39A	K. P. 9	Kauai	62.3	7.0	20	0.65
85	H. P. report 7	Oahu	N.D.	6.0	12	1.15
L4	H. P. 13	Lanai	N.D.	6.6	14	1.31
1	Libby 98-G	Molokai	74.9	6.5	13	0.95
71	Libby 98-D	Oahu	72.7	4.8	12	0.92
109	Libby 98-C	Oahu	N.D.	4.8	N.D.	0.47
KP5	K. P. 5	Kauai	74.6	4.8	16	0.47

The method of Bouyoucos includes some of the finer silt with the colloidal fraction, tending to make results too high. On the other hand, dispersion may not have been complete although the soil was stirred by an electric stirrer for 1 hour. The values as recorded show that the soils were highly colloidal, but all of them

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[3]Figures in parenthesis refer to "Literature Cited", p. 698.

have a mealy to fine crumb structure. The soils contain about 2% organic matter, are lateritic, contain in general less than 25% silica, and have a high fixing capacity for phosphorus.

Soil reaction was determined as recommended by de' Sigmund (3) in a 1:2 soil water suspension using the hydrogen electrode. Readily available phosphorus was determined as described by Truog (7), and potash by the method of Volk and Troug (8).

GREENHOUSE PROCEDURE

In Germany the greenhouse trials were conducted under the direction of Professor Mitscherlich following the method indicated in his publication (4) with the exception that the amount of the three plant foods, N, P_2O_5, and K_2O, added per pot varied in steps as follows: 0, 0.1, 0.25, 0.6, and 1.5 grams per pot. Each of the above plant foods was varied singly while the other two principal elements remained constant at 1.5 grams per pot. There were three pots to a treatment except in the case of complete fertilization where there were four replications. The crop grown was Lochows Petkuser Gelbhafer oats. Seeding occurred on May 6, 1931, and harvesting on August 17 and 19, 1931.

In Hawaii the author attempted to duplicate the greenhouse procedure of Professor Mitscherlich as closely as possible. Lochows Petkuser oats was obtained from Professor Mitscherlich and was used as the indicator crop. The plants were kept outside until heading occurred, except during periods of rain. Wind storms caused some lodging in the treatments receiving high nitrogen. The dates of seeding and harvesting varied with the soil used and will be discussed later. These Hawaii tests were conducted in the fall of 1932 and the spring of 1933.

RESULTS

The mean grain plus straw weights are recorded in Table 2 in percentage of the maximum yield. The maximum yield in grams, together with the mean standard error in grams, is also given so that the actual mean yield of a treatment, together with its standard error can be computed. In computing the standard error for a treatment the following formula was used: $\sigma = \sqrt{\frac{d^2}{n(n-1)}}$, where d = difference of a pot yield from the mean. The value 6 was used in the denominator where there were three pots receiving the same treatment. The mean standard errors as reported in Table 2 are means for a particular soil of the standard errors of individual treatment in grams.

DISCUSSION

Probably the most striking difference between trials in Germany and in Hawaii is that of lengths of time required for maturity. In Germany the oats were ripe 73 days after seeding, while in Hawaii this period ranged from 82 days to 172 days, depending on the date of planting. It is presumed that maturity is retarded in Hawaii at 21° North latitude because days are relatively short even in summer compared to length of days in summer at Konigsberg at a latitude of 55° North. The evidence in Table 3 also confirms this for oats grown during the longer days of May to July matured in 82 days, while oats grown during the winter required 149 to 172 days.

TABLE 2.—*Yields of oats on seven Hawaiian soils in Mitscherlich pot tests conducted in Germany and in the Territory of Hawaii.**

Grams plant nutrient added per pot	Field 39		Field 85		Field L4		Field 1		Field 71		Field 109		Field K.P. 5	
	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii
Nitrogen Variable														
0.0	5.8	9.4	7.5	18.1	17 7	22.3	6.6	13.8	5.1	16.1	5.3	10.1	8.6	19.6
0.1	9.5	18.3	14.5	26.8	27.2	32.6	11.5	20.4	8.9	23.6	11.6	22.7	13.8	30.0
0.25	21.6	32.5	26.0	39.7	37.3	42.3	19.0	36.5	19.5	34.5	23 9	44.1	27.4	42.5
0.6	45.8	48.8	57.9	53.9	56.5	62.7	47.2	51.6	47.9	52 6	52.7	73.1	59.8	68.0
1.5	100.0	100.0	100.0	100.0	100 0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Phosphorus Variable														
0.0	26.6	61.4	7.7	9.7	10.1	32.6	5.7	32.6	6.2	38.6	7 8	62.2	9.9	9.2
0.1	50.6	70.3	19.1	22.3	25.3	62.8	16.2	49.6	13.9	55.4	20.1	71.5	16.3	18.1
0.25	71.2	84 8	37.7	59.3	47.7	87.0	42.1	71.6	31.1	81.1	48.2	88.3	26.3	37.6
0.6	98.7	86.1	82.3	79 8	88.4	100.0	86.1	86 5	89.8	79.6	87.7	92 4	46.3	39.0
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100 0	100 0	100.0	100 0	100.0	100.0
Potash Variable														
0.0	87.1	82.4	78.7	106 0	89.2	106.8	82.8	83.5	71.1	84.4	73.3	92.4	62.7	92.9
0.1	75.0	78.5	81.3	89.7	82.5	107.3	84 7	94.9	75.4	86.2	81.6	94.2	74.6	93.5
0.25	86.6	88.0	82.4	94 9	89 9	107.7	82.1	98.4	83.2	88.7	82.0	91.7	76.7	94.7
0.6	89.7	84.5	89.6	97.6	91.0	108.8	85.3	95.1	85.4	85.8	91.0	99.2	84.8	98.6
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100 0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Actual weight complete, grams	133.0	120.7	134.1	110 7	152 7	122 7	143.5	151.7	128.1	146.7	120.0	79.3	123.8	51.3
Mean standard error in grams	3.38	2 42	3.15	1.48	2.90	1.59	2 95	2 21	2.23	1.96	2.50	1 55	1.37	.61

*Yields obtained with complete treatment are taken as 100% and other yields are given in percentage of this yield

TABLE 3 —*Length of time required for oats to mature in Germany and in Hawaii.*

Soil No.	Growing period, days	
	Germany	Hawaii
39	73	Dec. 15–May 11 (146)
85	73	Mar. 30–June 20 (84)
L4	73	Dec. 15–May 11 (146)
1	73	Oct. 27–Apr. 17 (172)
71	73	Oct. 27–Apr. 17 (172)
109	73	Jan. 25–June 15 (141)
KP5	73	May 4–July 15 (82)

The grain weight of oats grown in Germany was equal to about 40% of the straw plus grain weight. In Hawaii the grain weight was about 20% of the straw plus grain weight.

Reference to the mean standard error and the actual weights obtained with complete fertilization show that, in general, grain plus straw weights were greater in Germany. On the other hand, the yields of replicate pots agreed more closely in Hawaii.

With the exception of soil K. P. 5, the soils investigated contained large quantities of potash available to plants as shown by the Mitscherlich results (Table 2 and Fig. 3). Contrarily, the soils by the Mitscherlich test conducted in Germany and in Hawaii showed that these soils were markedly deficient in available phosphorus and nitrogen. Reference to Fig. 1 shows that results with nitrogen were strikingly similar in Germany and Hawaii.

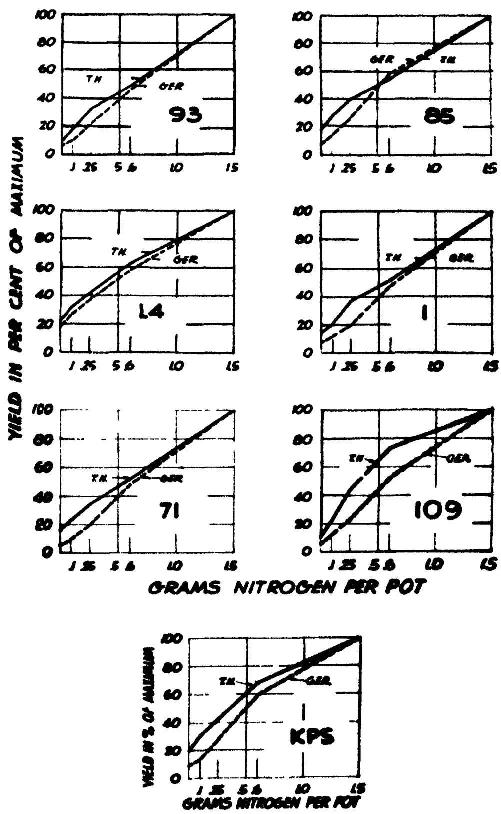

FIG. 1.—Grain plus straw yields on Hawaiian soils in Germany and in Hawaii with varying amounts of nitrogen added.

The results obtained in Hawaii differ from those obtained in Germany in one respect. In Hawaii the relative yields obtained with no phosphorus is far greater than the corresponding yields in Germany on the same soil. From the yields obtained without addition of phosphorus, the amount of root available phosphorus in the soil, the b value, can be calculated by means of the equation $b=\frac{\log A-\log (A-y_o)}{c}$, or by the use of tables (4). In the above equation A = maximum yield with large amounts of fertilizer variable added, expressed as 100%; y^o = yield obtained without addition of fertilizer variable, i.e., yield due to nutrient supply in soil, expressed as percentage of maximum yield A; and c = growth factor.

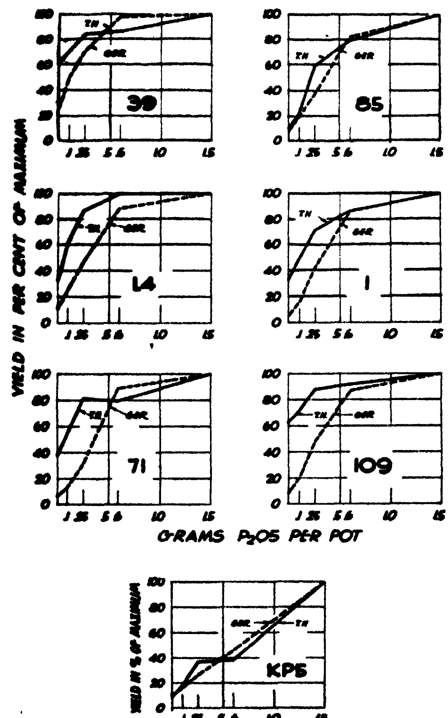

FIG. 2.—Grain plus straw yields on Hawaiian soils in Germany and in Hawaii with varying amounts of phosphorus added.

In calculating these b values, the growth factor c was assumed to be constant and when expressed in units of dz/ha to have the following values: N = 0.122; P_2O_5 = 0.6; and K_2O = 0.93.

The calculated b values, or amounts of available plant food in dz/ha of sand-soil mixture, are given in Table 4.

Inspection of Table 4 shows that the b value or amount of available plant food in the soil was found to be at least twice as great in the Hawaii tests as in the Konigsberg. Two explanations for this difference are given. They are, first, that under the higher Hawaiian temperature plant nutrients were more rapidly made available from the more complex soil materials, thus permitting a greater uptake by the plants in Hawaii in unit time. We know that organic matter conversion and formation of nitrates at a temperature of 25° C in Honolulu will proceed faster than at the lower soil temperatures of Konigsberg. A second explanation is that during the longer growing period of Hawaii of 140 days or over the plants were able to absorb more plant nutrients than in Germany in 73 days.

TABLE 4.—*The amounts in dz/ha of plant food available in sand plus soil mixture as indicated by Mitscherlich.**

Soil	Nitrogen (N)		Phosphorus (P_2O_5)		Potash (K_2O)	
	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii
39	0.21	0.34	0.22	0.69	0.96	0.81
85	0.26	0.70	0.06	0.07	0.72	4.00
L4	0.69	0.89	0.07	0.28	1.04	4.00
1	0.24	0.52	0.04	0.28	0.83	0.84
71	0.18	0.62	0.05	0.35	0.57	0.87
109	0.19	0.37	0.06	0.71	0.61	1.22
KP5	0.32	0.77	0.08	0.07	0.46	1.24
Mean values	0.30	0.60	0.08	0.35	0.74	1.85

*For dz/ha in field soil, multiply values by 6 (5)

The discrepancy between results in Hawaii and in Germany emphasizes that care must be used in the choice of indicator crop. If oats cannot be used in the tropics or sub-tropics, what crop can be used, and furthermore, if oats or some other crop has been selected as an indicator crop in one location, how far away, geographically or climatically, will comparative results be obtained with this same crop on the same soil?

The use of rice as an indicator crop under tropical conditions has been advocated. This crop, however, is sensitive to soil reaction (1).

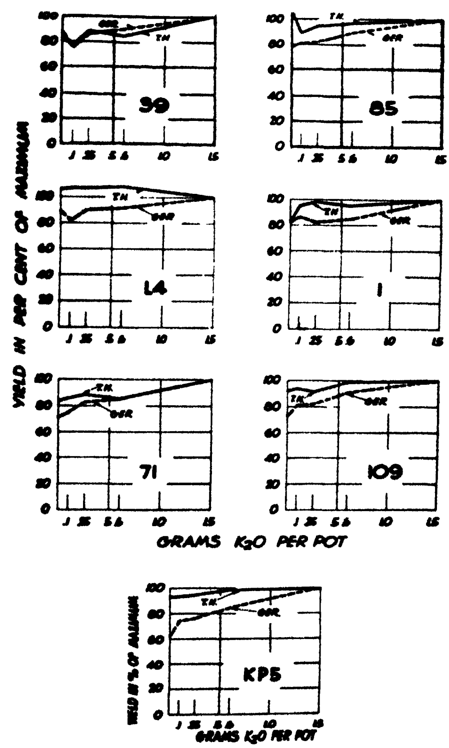

FIG. 3.—With varying amounts of potash added.

CONCLUSION

Seven soil samples from field experiments with pineapples in the Territory of Hawaii were each thoroughly mixed and half of each sent to Professor Mitscherlich, the other half being retained in Hawaii. These soils were all lateritic, contained a high colloid content, and fixed phosphorus readily.

At Konigsberg, Prussia, and also at Honolulu, Mitscherlich pot experiments were conducted as similarly as possible, using Lockows Petkuser oats in both cases.

In general, tests at both places showed the soils to be low in available nitrogen and phosphorus, while almost all soils were well supplied with available potash. The tests in Hawaii indicated that the natural store, or b value, for nitrogen and phosphorus was far greater than found in Germany. This may be explained by the much longer growing period in Hawaii and possibly by the greater rate of nutrient liberation at the higher Honolulu temperatures.

The comparison clearly shows that the indicator crop in this method of soil testing must be selected with particular reference to the locality involved.

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THE EFFECT OF SOIL TREATMENT IN STABILIZING YIELDS OF CORN[1]

L. B. MILLER AND F. C. BAUER[2]

EITHER failure or extreme over-production of a given crop is unfortunate both to farmers as a group and to society in general. The purpose of this paper is to point out the effect of soil treatment and of soil type upon the regularity or stability of corn production over a period of years and on several different soil conditions in Illinois.[3]

SOURCE OF DATA

The crop yield data used in this study were secured from the soil experiment fields operated by the Illinois Agricultural Experiment Station. Most of these fields were established during the years 1910 to 1915. The crops considered in the discussion are those of the 15-year period ending in 1935;[4] hence, the plats were well established by several years of preliminary cropping prior to 1920, the first season from which data for this particular study were used. Substitute crops or other irregularities occurred once during the period on five of the fields and an earlier year's yields were used to complete the 15-year sample This shift seemed justified because it was possible to secure an income by growing a crop other than corn. The fields were laid out so that each crop of the rotation used was represented each year. Most of the plats were one-tenth acre in size. A few fifth-acre and a few twentieth-acre plats were used.

SOIL TREATMENT

Plats 1, 5, and 10 in each series are untreated. Plats 2, 3, and 4 receive animal manure usually once during each 4-year rotation in amounts equal in weight to the crops removed. Plats 6, 7, 8, and 9 are designated "residue plats." They receive residual plant materials in the form of cornstalks, second growth clover, and a legume catch crop (usually sweet clover) wherever it can be conveniently used in the rotation. Applications of limestone are made as needed to plats 3, 4, 7, 8, and 9 (called the limed plats) and generous applications of rock phosphate were made to plats 4, 8, and 9 (the phosphate plats). Potash is regularly used on plat 9. Expressed by the usual symbols, the soil treatments on the entire series on all fields have been as follows: Plat 1, check; plat 2, M; plat 3, ML; plat 4, MLP; plat 5, check; plat 6, R; plat 7, RL; plat 8, RLP; plat 9, RLPK; and plat 10, check.

[1]Contribution from the Division of Soil Experiment Fields, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication May 4, 1938.

[2]Associate, Soil Experiment Fields, and Professor Soil Fertility, respectively.

[3]A similar paper concerning the wheat crop was presented by the authors in Jour. Amer. Soc. Agron., 29:728–734. 1937.

[4]Yield data published in Illinois Experiment Station Bulletins 273, 280, 296, 305, 327, 347, 370, 382, 398, 402, and 425.

EXPERIMENTAL RESULTS

Corn yields for the 15-year period ending in 1935 have been studied on 17 soil experiment fields in Illinois located as indicated on the map (Fig. 1). These fields are distributed over a range of latitude of more than 300 miles and include many distinctly different soil conditions. The plats were established primarily to study the effect of the soil treatment systems on crop yields and the economical use of land. They now offer, after these many years of cropping, a unique opportunity to study the stability of production on a given soil type, when unfertilized, and also with the various treatments used.

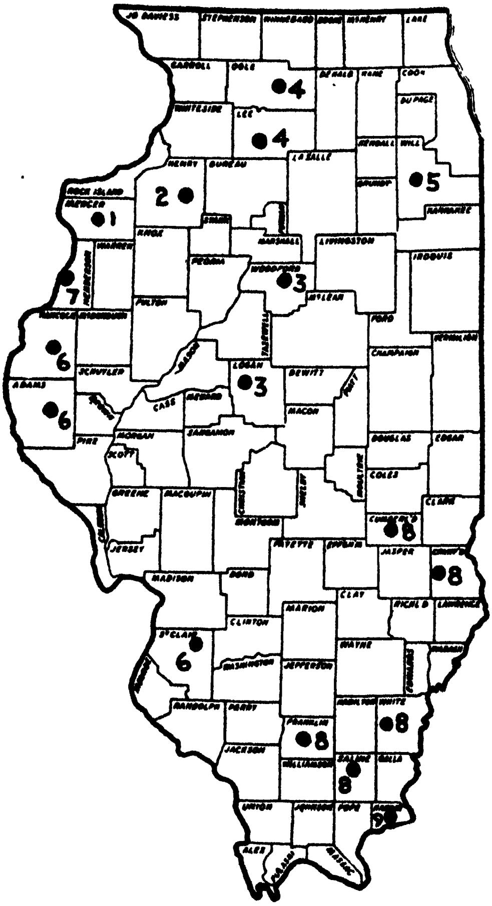

FIG. 1.—Location of the 17 soil experiment fields from which data were used. The numbers indicate the soil group represented by each field.

The 15-year average yield level for each treatment was calculated for each field. The annual variation in yield from this average was determined and reduced to a percentage of the average yield level. The average percentage of fluctuation for the 15-year period was calculated from the annual variation. Annual fluctuations exceeding 25% have been singled out for the purpose of discussion. They were usually distributed with approximately equal frequency above and below the average. The last column in Tables 1, 2, 3, and 4 gives the number of times in which the yields were below the 25% fluctuation level.

Further analysis of the fluctuation, either upward or downward, exceeding 25% of the average yield has been made to determine what portion of the total production is in each of these extreme ranges. This calculation has been reduced from bushels per acre to the basis of bushels per 1,000, and gives a direct measure of the extent to which

TABLE 1.—*Results at Hartsburg in Logan County, dark soil with heavy calcareous subsoil.*

Plat	Soil treatment	Average yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25–40	40–55	55–	
1	O	44.3	17.7	6	6	2	1	—	2
2	M	58.8	12.2	6	8	1	—	—	1
3	ML	66.6	7.4	10	5	—	—	—	0
4	MLP	65.6	10.0	7	8	—	—	—	0
5	O	48.4	16.0	7	5	2	1	—	1
6	R	64.9	13.5	5	9	1	—	—	1
7	RL	68.5	12.6	7	6	2	—	—	1
8	RLP	69.5	11.0	9	4	2	—	—	1
9	RLPK	65.9	12.7	8	5	2	—	—	1
10	O	51.9	14.6	5	8	2	—	—	1

TABLE 2.—*Results at Dixon in Lee County, dark soil with open, noncalcareous subsoil.*

Plat	Soil treatment	Average yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25 40	40–55	55–	
1	O	49.3	17.4	4	8	3	—	—	2
2	M	71.3	15.4	4	9	1	1	—	1
3	ML	76.1	12.9	7	7	—	1	—	0
4	MLP	76.0	12.8	7	7	1	—	—	0
5	O	49.7	21.1	2	9	3	—	1	2
6	R	57.1	18.2	4	7	3	1	—	2
7	RL	66.2	13.6	5	9	1	—	—	0
8	RLP	66.0	16.0	5	9	1	—	—	0
9	RLPK	72.6	14.8	5	9	1	—	—	0
10	O	48.7	19.6	5	5	4	1	—	2

a given soil or treatment has contributed to the production of a corn surplus or of a shortage.

Space does not permit the presentation of all of the data from the 17 fields studied, but Tables 1, 2, 3, and 4 give the summarized material for four widely separated fields which are typical for their respective soil and geographic locations.

The average corn yield fluctuations for the various treatments on the four fields are plotted in Fig. 2 and they indicate graphically the striking differences in stability of corn production for these soil conditions and treatments.

The extent to which each treatment on these four fields contributed to a surplus greater than 125% of its average yield is reported in

TABLE 3.—*Results at Lebanon in St. Clair County, dark soil with impervious noncalcareous subsoil.*

Plat	Soil treatment	Average yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25–40	40–55	55–	
1	O	36.7	36.1	3	4	1	4	3	5
2	M	47.2	32.6	1	6	3	2	3	5
3	ML	52.6	23.6	2	7	6	—	—	4
4	MLP	50.7	24.2	3	6	4	2	—	3
5	O	32.0	42.1	2	2	5	1	5	6
6	R	43.5	32.7	1	5	3	5	1	5
7	RL	55.5	23.1	3	6	4	2	—	3
8	RLP	57.3	21.6	4	6	3	1	1	2
9	RLPK	62.9	15.3	5	8	2	—	—	2
10	O	39.7	32.0	3	4	3	1	4	4

TABLE 4.—*Results at Ewing in Franklin County, gray soil with impervious noncalcareous subsoil.*

Plat	Soil treatment	Average yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25–40	50–55	55–	
1	O	8.4	65.9	1	2	2	0	10	7
2	M	22.4	54.2	1	2	1	5	6	7
3	ML	44.6	30.2	1	6	3	4	1	4
4	MLP	45.9	29.1	1	7	4	2	1	4
5	O	9.9	63 6	2	1	1	1	10	6
6	R	11.8	57.3	3	1	1	3	7	6
7	RL	19.2	50.5	1	1	3	3	7	7
8	RLP	22.8	47.6	2	1	4	3	5	7
9	RLPK	47.6	18.1	6	6	2	—	1	2
10*	O	—	—	—	—	—	—	—	—

*Discontinued before 1935.

Table 5. The results are tabulated as bushels per thousand. This calculation was made by singling out those seasons for each treatment when yields exceeded 125% of the 15-year average for that treatment. The number of bushels in excess of the 125% level were totaled and divided by 15 to get the annual average surplus production per acre for the entire period. This per acre figure was reduced to the "per thousand bushel" denominator so that plats having different average acre yields could be directly compared.

A similar procedure was followed to determine the tendency and extent of each plat's failure (below the 75% level) to produce an average crop. This is in line with the method devised by the U. S. Dept.

TABLE 5.—*Surplus production above 125% of average yield per 1,000 bushels.*

Plat	Treatment	Ewing, bu.	Lebanon, bu.	Dixon, bu.	Hartsburg, bu.
1	O	238.1	96.7	19.3	7.9
2	M	165.2	53.2	13.0	0.0
3	ML	28.0	10.1	17 0	0.0
4	MLP	26.1	19.1	7.0	0.0
5	O	209.1	100.9	24.7	17.1
6	R	174.6	44.1	14.2	0.0
7	RL	147 9	11.0	5.1	2.2
8	RLP	152 2	19.0	7.0	1.4
9	RLPK	2.9	0.0	11.6	0.5
10	O	——	69.8	16.0	8.1

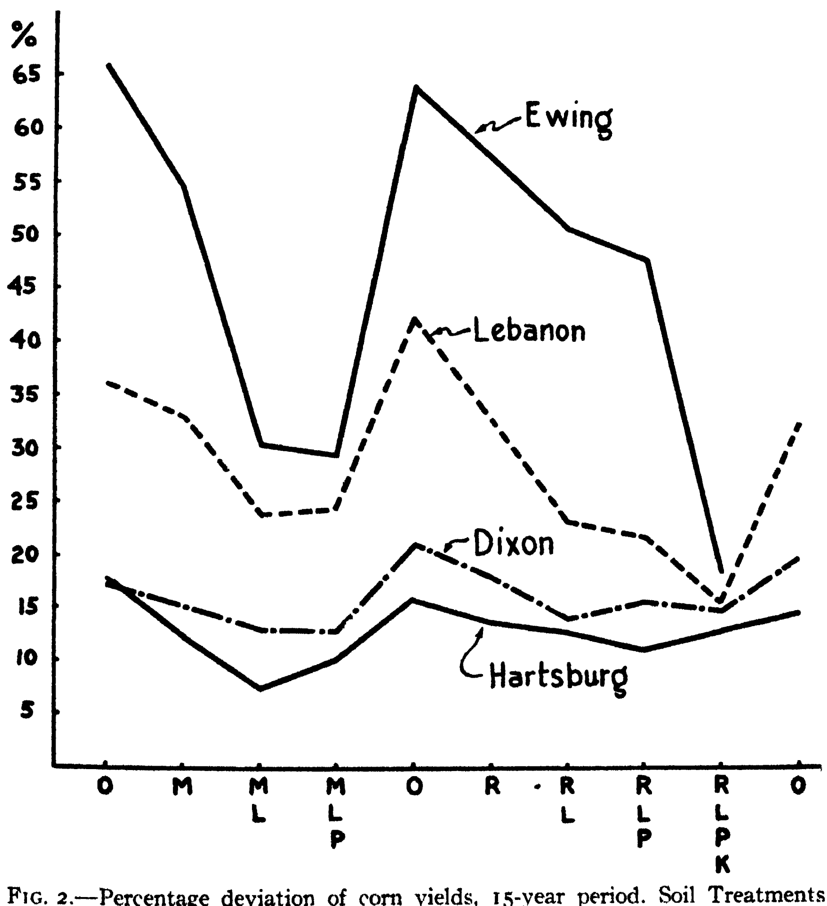

FIG. 2.—Percentage deviation of corn yields, 15-year period. Soil Treatments indicated at bottom of graph.

of Agriculture[5] for the determination of insurance premium rates under the recently suggested plan for crop insurance. The data from any given plat might be thought of as a basis for determining rates for farmers using soil and treatments similar to that of the particular plat. The failures were reduced to the "per thousand bushel" basis as described above, and the results shown in Table 6 are the actual loss costs on all coverage insurance for 75% of average yields.

TABLE 6.—*Loss cost of 75% coverage insurance per 1,000 bushels.*

Plat	Treatment	Ewing, bu.	Lebanon, bu.	Dixon, bu.	Hartsburg, bu.
1	O	198.9	83.7	8.7	17.8
2	M	153.1	64.2	1.8	7.0
3	ML	72.9	22.4	0.0	0.0
4	MLP	66.4	27.4	0.0	0.0
5	O	210.1	104.1	7.8	8.1
6	R	188.1	69.0	12.8	7.4
7	RL	120.3	40.4	0.0	1.0
8	RLP	101.3	30.2	0.0	3.7
9	RLPK	34.7	13.1	0.0	9.1
10	O	—	57.2	19.5	0.4

Perhaps this can be made clearer by the use of an illustration involving two farmers operating land such as that of the Ewing field. Let us assume that farmer No. 1 follows the method of plat 1 (no treatment) and farmer No. 2 uses the soil treatment of plat 4 (MLP). Each man has insurance which guarantees him a 75% crop and whenever his yield falls below that level he is to receive payment in bushels of corn sufficient to bring his yield up to the 75% level. To secure this protection he pays premiums, also in corn, and in amount equal to the indemnities he would collect. The premium or insurance cost of farmer No. 1 (plat 1), based on 15 years' results at Ewing, would have been 198.9 bushels of corn out of every 1,000 bushels he had grown, while the insurance cost of farmer No. 2 (plat 4) would have been 66.4 bushels per thousand, or approximately one-third as great. The loss cost of 75% coverage insurance on this basis for all plats at Ewing and on three additional fields are reported in Table 6 and give a good measure of the risk associated with growing corn on the different soils as they were treated. There were two plats at Hartsburg and five plats at Dixon on which production never fell below the 75% average during the entire 15-year period.

The soils of the 17 fields used in this study are representative of nine soil groups. These groups, together with the names of the fields in each, are as follows:

Group 1. Dark soils with heavy, noncalcareous subsoils.
Aledo, Mercer County.

Group 2. Dark soils with noncalcareous subsoils.
Kewanee, Henry County.

[5]75th Congress, 1st Session, House Document No. 150.

Group 3. Dark soils with heavy calcareous subsoils.
Hartsburg, Logan County.
Minonk, Woodford County.

Group 4. Dark soils with open noncalcareous subsoils.
Dixon, Lee County.
Mt. Morris, Ogle County.

Group 5. Dark soils with heavy, impervious, calcareous subsoils.
Joliet, Will County.

Group 6. Dark soils with impervious, noncalcareous subsoils.
Carthage, Hancock County.
Clayton, Adams County.
Lebanon, St. Clair County.

Group 7. Sandy loams and sands.
Oquawka, Henderson County.

Group 8. Gray and yellowish-gray soils with impervious noncalcareous subsoils.
Enfield, White County.
Ewing, Franklin County.
Oblong, Crawford County
Raleigh, Saline County.
Toledo, Cumberland County.

Group 9. Hilly, forest, orchard and pasture land.
Elizabethtown, Hardin County.

It is unfortunate that some of the soil groups are represented by only one field. However, the similarity of performance of individual fields within those groups having more than one representative indicates that each field is a fairly reliable sample. The average yields and percentages of fluctuation for the soil groups are given in Tables 7 and 8. The groups are arranged in the order of decreasing yields on the untreated plats.

DISCUSSION OF RESULTS

Corn grown on fertile dark-colored soils was consistent in producing high yields. The results secured at Hartsburg (Table 1) and Dixon (Table 2) are typical of the better corn-belt soils of Illinois. The average percentage of fluctuation was low even on the untreated plats and was reduced approximately one-fourth by treatment. During the 15-year period at Dixon the greatest downward fluctuation on the limed plats was 24.5%. In contrast to this each of the untreated plats had two seasons when downward fluctuation exceeded 25% with a maximum of 40.9% on plat 10.

The soil at Lebanon in St. Clair County is also dark in color but has an impervious subsoil and, while it frequently produced high yields of corn, it was much less reliable in this respect than the better-drained dark-colored soils of the central and northern part of the state. Another factor which contributed to irregular production at Lebanon was the rather frequent and serious damage done by chinch bugs. Corn yields on plat 9 (RLPK) showed the least fluctuation, the

TABLE 7.—*Yields of corn in bushels per acre for soil groups, 15-year average.*

Soil treatment	Soil group numbers								
	2	1	4	3	6	5	7	8	9
O	56.0	49.4	50.1	46.7	37.7	33.3	20.9	16.0	—†
M	71.8	65.5	69.8	60.3	52.6	45.6	30.7	27.8	21.6
ML	76.5	68.5	75.3	65.0	61.0	51.3	42.8	44.7	38.1
MLP	77.5	68.5	75.2	64.2	62.1	50.9	43.5	45.3	42.3
O	56.3	54.8	48.2	48.8	37.8	31.2	22.1	15.4	10.3
R	64.0	63.5	56.0	62.9	49.9	35.7	25.1	19.0	13.5
RL	70.2	75.1	66.7	66.0	61.7	39.9	40.1	28.1	33.2
RLP	73.6	76.7	67.2	67.4	63.0	46.9	40.3	30.6	42.3
RLPK	75.0*	78.5	72.2	64.5	67.7	50.1	41.0	45.8	43.1
O	—†	54.1	47.4	49.0	42.2	31.6	21.9	—†	—†
Average of untreated plats	56.1	52.8	48.6	48.2	39.2	32.0	21.6	15.7	10.3

*Chinch bug injury.
†Plat discontinued before 1935.

TABLE 8.—*Yield fluctuations for soil groups, 15-year average percentages.*

Soil treatment	Soil group numbers								
	2	1	4	3	6	5	7	8	9
O	22.0	22.1	19.7	15.8	26.9	25.0	42.3	50.1	—†
M	14.4	25.1	16.9	13.0	24.0	20.3	33.5	38.1	52.5
ML	15.0	21.0	12.9	9.9	18.7	14.9	33.4	24.8	31.9
MLP	14.4	20.5	13.1	12.3	19.0	15.9	35.3	24.9	19.8
O	19.8	21.0	21.2	17.0	29.9	27.8	46.5	46.3	75.6
R	17.3	19.4	17.8	14.7	24.6	25.8	41.2	39.1	61.7
RL	18.3	11.2	15.3	13.9	20.4	18.5	36.2	33.4	25.9
RLP	17.1	11.3	16.3	14.0	19.6	17.1	39.0	33.2	21.9
RLPK	19.3*	13.8	17.3	14.4	17.2	16.5	39.5	20.8	25.6
O	—†	19.9	18.9	16.9	24.7	30.4	47.1	—†	—†
Average of untreated plats	20.9	21.0	19.9	16.6	27.2	27.7	45.3	48.2	75.6

*Chinch bug injury.
†Plat discontinued before 1935.

average being only 15.3%. The average fluctuation on the untreated land was 36.7%, while the average for the limed plats was 21.6%. On the untreated plats downward fluctuations exceeding 25% occurred five times during the 15 years. The average on the limed plats was slightly less than three such fluctuations during the period.

At Ewing (Table 4) which is typical of the gray, poorly-drained soils of group 8, the yields on untreated land were very low and fluctuated greatly, the average being 64.7% with downward variations greater than 25% occurring during nearly half of the seasons. However, an average yield of 47.6 bushels an acre was secured on plat 9

(RLPK) with an average fluctuation of only 18.1% and but two seasons when the downward fluctuation was more than 25%. Plat 4 (MLP) ranked next to plat 9 in this respect with four low-yield seasons and an average variation of 29.1%.

On hilly land at Elizabethtown in Hardin County the use of limestone with phosphate and organic matter supplied either as stable manure (MLP) or as green manure (RLP) greatly increased the reliability of corn production. However, these better plats were considerably lower in both yield and dependability than was the case on the untreated dark-colored soils of the corn belt.

Corn yields on sandy land at Oquawka were approximately doubled by the use of limestone and organic matter, but fluctuation was high, even on the best yielding plats. Plat 4 (MLP) produced 43.5 bushels an acre for the highest average yield, but had an average fluctuation of 35.3%.

The average production of surplus per thousand bushels for each plat, as described above, is recorded in Table 5. The greatest variation in this respect between plats on the same field was at Ewing, where, on the first untreated plat, 238.1 bushels per thousand or more than one-fifth of the crop was in the surplus group. In contrast to this, only 2.9 bushels of surplus per thousand was produced on plat 9 (RLPK), there being only one crop on this plat which yielded in excess of 125% of the average and that excess was only 2.1 bushels. Production on one of the untreated plats at Ewing was in excess of the 125% level six times during the 15 years, while the other untreated plat had five such excess yields.

At Lebanon no surplus greater than 25% was produced on plat 9 (RLPK) In contrast to this, the average surplus production of the three untreated plats was 89.1 bushels per thousand.

On the better dark-colored soils represented by Dixon and Hartsburg, there was very little surplus production of corn above the 125% average yield level, the average on untreated land being only 20 bushels per thousand at the former and 11 bushels per thousand at the latter field. Treatments on both of these fields reduced, even below this low level, the number of surplus bushels produced. At Hartsburg four of the treated plats produced no surplus yields during the entire 15 years observed.

The data in Table 5 have shown the extent to which soils and treatments have contributed to excessive corn production above a yield level 25% higher than the average of each plat. Table 6 may be thought of as being the converse of Table 5 in so far as it shows the extent to which production on a given plat failed by more than 25% to equal the average for that plat. The bushels reported in Table 6 might, as suggested above, be thought of as appropriate 75% coverage insurance premiums per thousand bushels of corn grown with the various soils and treatments.

By totaling the items from Tables 5 and 6 for a given plat, we have a measure, based on 15 years' results, of the bushels per thousand which that plat contributed to all yield variations exceeding 25% of its 15-year average yield.

GENERAL COMMENTS

During the 15-year period studied a number of irregularities in procedure have occurred which should be recognized. The crop rotation was altered slightly on some of the fields and a few changes were made in varieties of corn used. In some instances the method and amount of fertilizer application was varied but the same general treatment for each plat was continued throughout the entire 15-year period and for several seasons prior to 1920, the first season from which data were used. This preliminary cropping tended to establish the yield for each treatment at a level near which it was maintained during the 15 years studied. Undoubtedly there were some unnoticed irregularities due to damage by rodents or insects or other causes on portions of plats or fields. Where irregularities were noticed, they were either corrected or noted in the tables.

No attempt has been made in this paper to correlate yield irregularities with weather conditions or other specific factors which may have caused them.

CONCLUSIONS

1. The fertile, dark-colored, corn belt soils produced high yields of corn with a high degree of regularity from year to year.
2. Corn production was very irregular on untreated land of low fertility.
3. Stability of corn production was greatly improved by soil treatment on all of the poor or moderately fertile soils studied except the sandy soil where treatment raised the yield level but caused only a slight reduction in yield fluctuation.
4. The most successful treatments on the poor and intermediate soils failed to bring either their average yield or regularity up to the level of the treated plats on the better soils. However, in many cases their performance did excel that of the untreated plats of the better soil groups.
5. Surpluses and losses exceeding 25% of the average yield were produced at least once during the 15 years on all untreated land, even on the best soils studied.
6. Surpluses and also losses exceeding 25% were so great on the poorer untreated land that in some cases they totaled more than one-fifth of the entire production.
7. Good soil and good farming methods are in themselves very good corn crop insurance under Illinois conditions.
8. Farmers who practice good farming methods will have few seasons of extreme surplus yields and are in a good position to predict the amount of their corn production.

AGRONOMIC AFFAIRS

THE SOIL SCIENCE SOCIETY OF AMERICA

A call for papers for the annual meeting of the Soil Science Society of America, November 15 to 18, 1938, has been issued by the Secretary, Dr. W. A. Albrecht of the University of Missouri. Titles of papers to be presented at the meeting should be in the hands of the respective Section chairmen at an early date. The chairmen and their addresses are as follows:

Section I. Soil Physics

L. A. RICHARDS . . . . Iowa State College, Ames, Iowa.

Section II. Soil Chemistry

E. E. DETURK . . . . Univ. of Illinois, Urbana, Illinois.

Section III. Soil Microbiology

N. R. SMITH . . . . Bur. Plant Industry, Washington, D. C.

Section IV. Soil Fertility

H. J. HARPER . . . . Oklahoma A. & M. College, Stillwater, Okla.

Section V. Soil Morphology

W. E. HEARN . . . . Bur. Chem. & Soils, Washington, D. C.

Section VI. Soil Technology

E. A. NORTON . . . . Soil Conservation Service, Des Moines, Iowa.

Papers for the PROCEEDINGS will be limited to 5,000 words, with a surcharge for all beyond this figure. Abstracts will also be desired in advance of the meeting. Communication with your Section chairman will facilitate the placement of your paper on the program.

SUMMER MEETING OF CORN BELT SECTION

ABOUT 150 agronomists, representing 14 states, the U. S. Dept. of Agriculture, and Australia, participated in the summer meeting of the Corn Belt Section of the Society at the University of Missouri on June 22 and 23. Several arrived in time to witness the celebration of the fiftieth anniversary of the founding of the Missouri Experiment Station on June 21.

One day of the meeting was spent inspecting agronomic work in progress at Columbia, while the second day was devoted to a tour of outlying experimental tracts.

An invitation from the Ohio Experiment Station to hold the 1939 meeting in that state was accepted.

NEWS ITEMS

TWO HUNDRED farmers from all sections of Florida attended the recent All-Florida Pasture Conference at the University of Florida

College of Agriculture in Gainesville. The first conference of its kind in Florida, it was held for the purpose of bringing together farmers, agricultural workers, and farm finance agencies to work out a program for pasture development in the state. Outstanding features included a tour of pasture and live-stock experimental work being done by the Florida Agricultural Experiment Station, discussions and addresses by Dr. H. Harold Hume, Experiment Station research official; H. R. Smalley, agronomist for the National Fertilizer Association; H. S. Johnson, Farm Credit Administration official; and others. Dean Wilmon Newell presided at the conference.

DOCTOR M. F. MILLER, Dean of the Missouri College of Agriculture and Director of the Experiment Station, was given the honorary degree of Doctor of Science by the Kansas State College at the seventy-fifth anniversary commencement of that institution.

FOR THE FIRST time in the history of this country an American peat moss, produced on a commercial scale, will be placed on the market. A company known as the American Peat Company has begun operations on a 1,300-acre highmoor sphagnum peat bog known as the Denbo Heath and located near the town of Deblois, north of Cherryfield, Maine.

DOCTOR F. D. RICHEY, formerly Chief of the Bureau of Plant Industry and a past President of the Society, is now located at Ashville, Ohio, where he is engaged in the commercial production of corned hybrids.

soil was relatively moist upon entering the machine and seemingly dry at the end of the exposures, the drought was essentially an atmospheric one. Because of the elimination of water just previous to treatment, the plants may have hardened off to some extent.

Nine pots of each of the forage varieties in the sod group and in the 30-day old seedling group were grown. Eight pots were used for treatments and one as a check. For the 60-day old seedlings six pots were used for treatments and one as a check. All pots were randomized within growth stage groups and embedded into the soil in the bench for growing as an aid in obtaining uniform greenhouse environmental conditions.

For the 30-day old seedlings there were four replications of the 10-hour treatment and two each of the 16- and 20-hour treatments. The 60-day old seedlings had two replications for each of the 10-, 16-, and 20-hour treatments, while for the sod plants two replications were used for the 16- and 20-hour treatments and four for the 26-hour treatment.

A record of temperature and percentage of relative humidity was made every few hours during the various trials. The ultimate temperature of each test was about 43° C, with a relative humidity of about 17%. After treatment, the plants were again placed on the greenhouse bench in position with their checks for two weeks before readings were made of drought injury.

The seedling pot or unit represented a relatively large number of young individuals, while the sod was a mass of plant material of a definite size rather than a number of plants or tillers. The same injury reading scale therefore did not lend itself well for comparable readings. The following scale was used for the seedlings:

0—All plants completely killed.
1—From 1 to 5% of plants showing some life.
2—From 6 to 20% of plants showing some life.
3—From 21 to 33% of plants showing some life.
4—From 34 to 50% of plants showing some life.
5—From 51 to 66% of plants showing some life.
6—From 67 to 80% of plants showing some life.
7—From 81 to 100% of plants showing some life.
8—All plants alive with leaves injured severely.
9—All plants alive with tips of leaves dead.
10—No injury; comparable to check.

The scale used for the sod material was made with the following seven classes.

0—All plant material dead.
1—Very slight recovery.
2—Weak recovery.
3—Fair recovery.
4—Medium recovery.
5—Good recovery.
6—No injury; equal to check.

Peto (6) used a number of methods, including the drought chamber, in testing drought injury during early and late stages of plant growth. He found a diurnal effect which was caused especially by period variations in sunlight.

The Russian workers have studied drought resistance rather intensively. Aamodt and Johnston (2) and Peto (6) have reviewed the Russian literature which deals with crop plants, especially wheat.

In studies on the nature of drought resistance on a physico-chemical basis, Newton and Martin (5) arranged a number of grasses in order of drought resistance as indicated by their bound water percentages. Some of these species and percentages were crested wheat grass, 11.7; slender wheat grass, 10.3; brome grass, 10.3; Kentucky bluegrass, 5.3; and timothy, 4.5. Inter-annual correlation for bound water percentages gave an r value of 0.82 ± 0.06.

MATERIALS AND METHODS

The plant material used in this study was of three sorts—sod pieces, brought into the greenhouse about the middle of November and transplanted into pots, 60-day old seedlings, and 30-day old seedlings started in the greenhouse. All plants were grown in 4-inch clay pots containing a uniform soil mixture. The sod pieces were broken down to sizes of about 1 inch in diameter, while the 60-day seedlings were transplanted once from flats to pots and the 30-day seedlings were seeded directly into pots. There were varying numbers of plants per pot for these different forages, but it seemed that this was not a seriously disturbing factor in the testing.

Forage species and varieties that were under trial in the Minnesota Experiment Station pasture studies were used in this drought test. The sod group contained the following material: Commercial and pasture type timothy, forage and Fairway strains of crested wheat grass, commercial and non-creeping brome grass, Canada and Kentucky bluegrass, red and brown top, reed canary grass, meadow, creeping, and chewings fescue, meadow foxtail, slender wheat grass, orchard grass, Grimm alfalfa, and alsike clover. The two seedling groups contained the above material except slender wheat grass, reed canary grass, and brown top, and included, sweet, red, and white clover.

Through the courtesy of Dr. Shirley, the Lake States Forest Service drought machine was made available for the study of drought resistance of these forage grasses and legumes. This machine has a rotating platform upon which the plants are placed. Temperatures are raised by electric heating elements and also by electric bulbs which are used for lighting. Humidity is reduced rapidly by exhausting the heated atmosphere from the machine and also by the use of a calcium chloride dehydrating chamber. The wind velocity was held constantly at a rate of approximately 5 miles per hour.

Preliminary treatments of various durations were tried in order to find the treatment giving the best differential. The treatment conditions in the machine were similar for all trials, the only difference being in length of time of exposures. The pots were uniformly and heavily watered approximately one week before treatment and not again until immediately after removal from the machine. While the

ARTIFICIAL DROUGHT TESTS OF SOME HAY AND PASTURE GRASSES AND LEGUMES IN SOD AND SEEDLING STAGES OF GROWTH[1]

H. K. SCHULTZ AND H. K. HAYES[2]

DROUGHT resistance is important in hay and pasture grasses and legumes during all stages of growth. In the seedling stage resistance to drought may be of great importance in maintaining a stand after emergence. In many cases successful seedling stands of forages from early spring seeding have been killed in recent years in the early or late summer by severe hot and dry weather. Resistance to drought in later stages of growth may aid materially in maintaining established stands.

The studies reported here are a comparison of resistance under artificial trials in both the seedling and sod stages with behavior under field conditions.

LITERATURE REVIEW

Shirley (7, 8, 9)[3] has carried out numerous artificial drought tests on conifers. He studied seedlings from one to several years old and determined the length of treatment that produced death. The results of laboratory machine tests of drought resistance and of field survival during extremely dry periods are in good agreement. A description of the drought machine used and methods of handling plant material, together with results of tests, is given by Shirley and Meuli (9).

A machine was built in 1935 by Aamodt (1) for testing the resistance of wheat plants to drought. Atmospheric drought conditions were produced which were similar to those in the dry area of Alberta where young wheat plants often are injured severely. Wheat varieties which were known to be drought resistant under field conditions were less severely injured under artificial test than varieties known to be nondrought resistant.

Aamodt and Johnston (2) conducted an extensive test on spring wheat varieties. Three factors were considered to be of major importance in drought resistance, *viz.*, the ability to evade early periods of drought, capacity of developing root systems rapidly in the early stages of growth, and superior capacity to endure drought without permanent injury.

Bayles, Taylor, and Bartel (3) studied the drought resistance of eight wheat varieties comparing injury from the use of a hot-air blast over plants placed on a revolving table with the relative rates of water loss from cut plants. They found good agreement between various replicates in the artificial tests. Variety evaluations were consistent with field performance under drought conditions.

Artificial heat and drought tests were made on inbred strains of corn by Hunter, Laude, and Brunson (4). Susceptible firing lines under field conditions showed heavy injury due to treatment while the resistant lines showed little or no injury. Temperatures of approximately 140° F and a relative humidity of about 30% were used. The various tests gave consistent results and agreed well with field trials.

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[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1606 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication April 28, 1938.

[2]Instructor and Chief, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 681.

3. McCLINTOCK, BARBARA, Cytological observations of deficiencies involving known genes, translocations and an inversion in *Zea mays*. Mo. Agr. Exp. Sta. Res. Bul. 163. 1931.
4. RICHEY, F. D., and SPRAGUE, G. F. Experiments on hybrid vigor and convergent improvement in corn. U. S. D. A. Tech. Bul. 267. 1931.
5. STURTEVANT, A. H. Autosomal lethals in wild populations of *Drosophila pseudoobscura*. Biol. Bul., 63:542–551. 1937.

genetic factors located in chromosome 1. If the frequency of the p p plants is significantly less than the expected value, the presence of a genetic factor, or factors affecting viability in chromosome 1 of the inbred line under test can be assumed.

The same inversion strain may be crossed with as many inbred lines as practicable and the yields of the recessive and dominant classes compared in all the crosses. If, for example, the recessive class yields 10 bushels per acre less than the dominant class when inbred A is used and only 5 bushels less when inbred B is involved, the data signify that inbred B carries a more favorable assemblage of genes in its chromosome 1 than inbred A does. When tests for many different lines are available it should be possible to identify that line, or those lines, which have the most desirable complement of genes in chromosome 1. If inversions were available covering all regions of the 10 chromosomes of maize, one could make a complete analysis of the genotype of any inbred line with regard to yield and other characters. Admittedly, this is a ponderous task, but one not beyond the range of possibilities in practice.

A somewhat different situation is met with when individual plants of an open-pollinated variety, rather than inbred lines, are to be tested. In a cross of the inversion strain by single individuals of a variety no two plants in the first generation are likely to have the same genetic constitution. It follows that the F_2 progeny from every F_1 plant must be tested separately. This means that a limited quantity of seed is available for testing. Whenever more seed is necessary the F_1 plants can be backcrossed to the inversion strain and the inversion homozygotes compared with the heterozygotes. In backcrosses with the inversion strain a test is made only for dominant genes located in chromosome 1 of the open-pollinated plant. If a recessive mutant gene rather than a dominant were included within the inversion, the recognition of the two classes would be facilitated. It is probable that the testing of the inbred lines would be more profitable and simpler, but both procedures may be required in a large breeding program.

Collections of lines known to carry desirable groups of genetic factors in definite chromosomes may be accumulated. These lines could be used as reservoirs of such factors. The problem of combining specific chromosomes from different strains into a single line presents certain technical difficulties that will not be discussed here. It will be a tedious task. We may point out, however, that even before this is done the method of localizing yield factors in definite chromosomes will be of service to the breeder. The ability to describe the genetic constitution of the inbred lines cannot but be helpful to him.

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parent that the extent to which the presence of an inversion causes the genes in a chromosome to be inherited as a unit depends directly upon the frequency of certain types of crossovers. The information available in *Drosophila* shows that different inversions behave differently in this respect. One should note, however, that all inversions, except perhaps only the very short ones, decrease the frequency of crossing-over not only in the inverted segment, but likewise in the parts of the chromosome having identical gene orders but adjacent to the points of breakages.

Unfortunately, there is very little published information on the effects of inversions on crossing-over in maize. The cytological observations of McClintock (3) suggest, however, that at least some of the inversions in maize may behave similarly to some of those known in *Drosophila*. Although beyond doubt much remains to be done before suitable inversion-carrying strains can be developed in maize that would permit the localization of groups of desirable genetic factors, the task is by no means hopeless.

Inversions in maize are known to occur spontaneously, and they have been produced by X-ray irradiation. We may venture to outline the following scheme of work, subject to such modifications as experience will suggest. An inbred strain of maize carrying as many dominant mutant genes in as many different chromosomes as possible is to be treated with X-rays. The dominant genes will serve as chromosome markers. Evidently the genes must be so chosen as to be easily classifiable in hybrids with all or with most of the maize strains of commercial importance. The irradiation will produce inversions. Some of them will include those regions of different chromosomes marked by a dominant mutant gene. The extent of the inversions, as well as their effects on crossing-over, must subsequently be determined both genetically and cytologically.

Let us assume that an inversion in chromosome 1 including the dominant *P* gene is produced and that a stock homozygous for this inversion is obtained. This stock is then crossed with different inbred lines or with individual plants of a variety carrying the recessive *p* gene. Further procedure will depend upon whether an inbred line or an individual plant of a variety is to be used in the cross. Consider first the cross with an inbred line. The F_1 generation from the cross of the inversion strain by an inbred line will be uniform. On selfing a segregation into a 1:2:1 ratio is expected in F_2. One quarter of the F_2 plants, namely, those homozygous for *p*, carry in duplicate the chromosome 1 of the inbred line. The plants with the dominant *P* character are either homozygous or heterozygous for the inversion. These two classes usually can be distinguished because some aborted pollen is produced in most inversion heterozygotes (due to crossing-over, see above). Alternately, a backcross of the F_1 plants to the inbred parent results in a segregation of a 1:1 ratio. In either eventuality, the yield and other characteristics, such as lodging of the two classes of plants, are compared. The members of the two classes will occur at random within the progeny. Any statistically significant difference for any specific characteristic between the means of the two classes, which differ only by their chromosomes 1, is attributable to the effects of

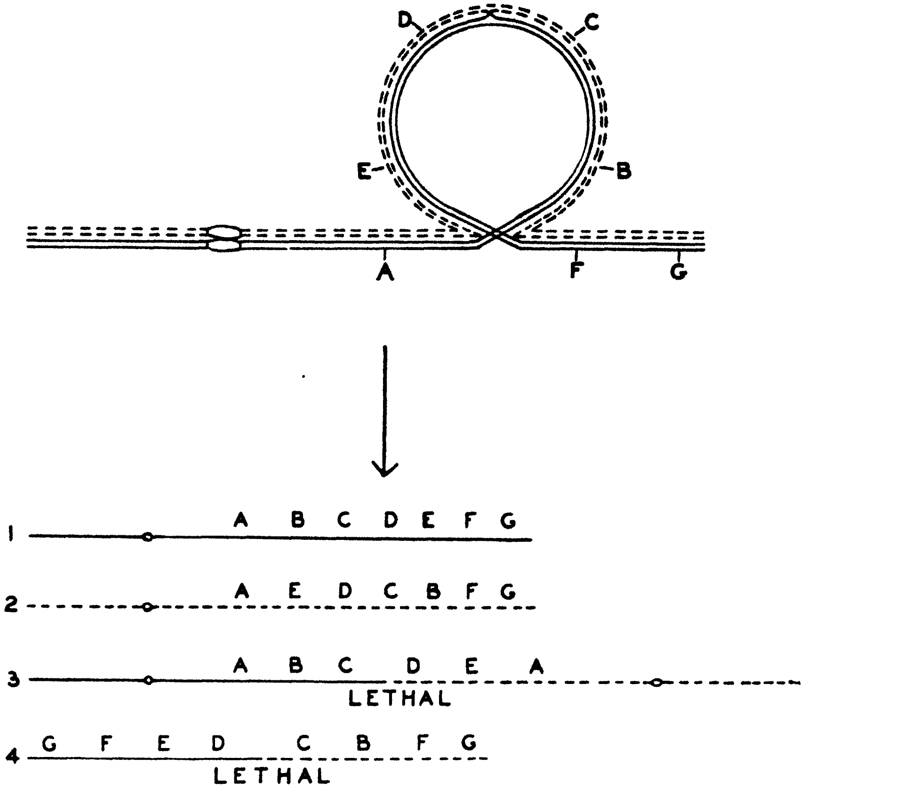

FIG. 2.—Diagram illustrating synapsis in an inversion heterozygote. The two chromatids represented by unbroken lines have the normal gene order A B C D E F G while in the two chromatids of the homologous chromosome, shown by broken lines, the order is A E D C B F G. The loop formed, when pairing occurs between all loci, includes those genes included in the inversion. A single crossover in the inverted region is shown between genes C and D. The products of this crossover are shown below. Chromatid 1 with the normal gene order and chromatid 2 with the inverted order are identical with the two parental chromosomes as far as loci within the inversion are concerned They are viable because they have a full complement of genes. Chromatids 3 and 4 are both crossover strands and are non-viable since they have both duplications and deficiencies. Chromatid 3 had two spindle insertion regions while chromatid 4 has none. Since all crossovers, save certain types of rare multiples, within the inversion lead to non-viable chromosomes similar to 3 and 4 the group of genes within the inverted region are inherited en bloc.

others in duplicate. Such chromosomes are, as a rule, non-viable. If two crossovers occur within the inverted region and if the same two chromatids are involved at both points of crossing-over, chromosomes with a normal gene complement are obtained. They possess in the inverted region a block of genes derived from the homologous chromosome. Certain other types of double and multiple crossovers likewise produce viable chromosomes with a full gene complement but with blocks of genes obtained from homologous chromosomes. It is ap-

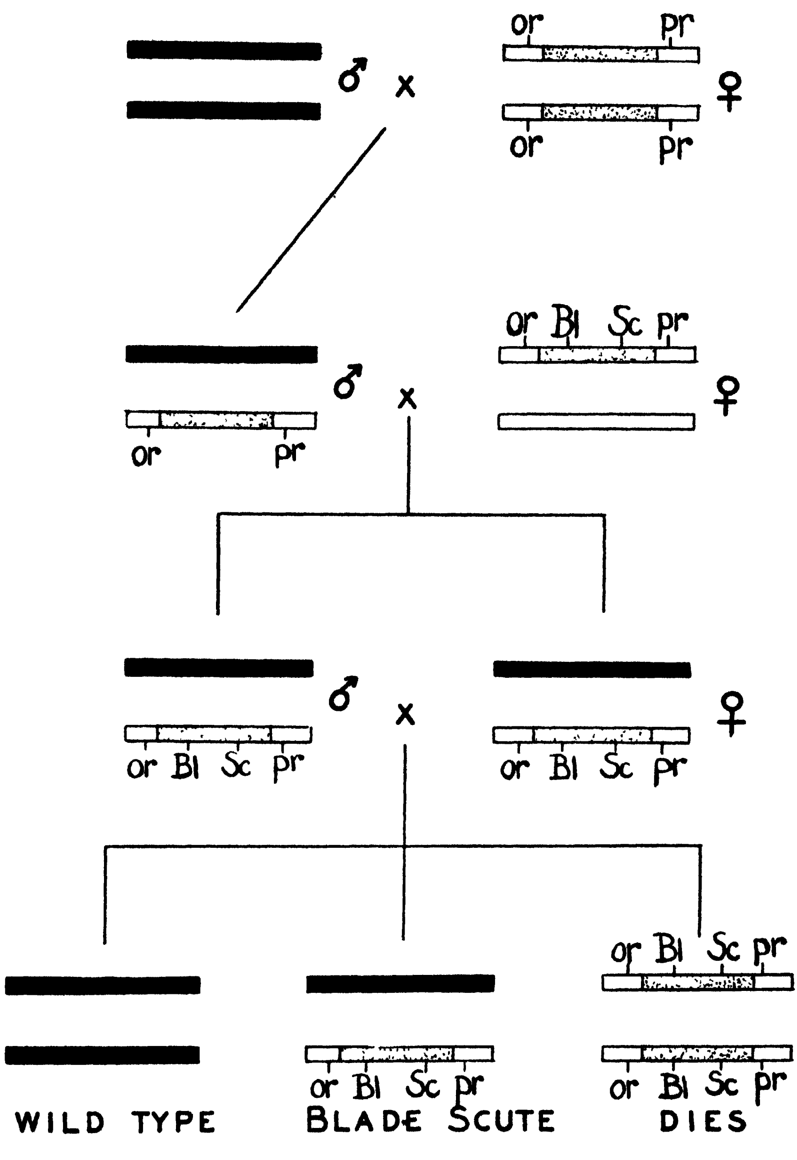

FIG. 1.—Experimental procedure for the detection of the genetic variability in the third chromosome of *Drosophila pseudoobscura*. Chromosomes to be tested are shown in black, the tester chromosomes in white, the inverted sections in the tester chromosomes by stippling.

cussed here, has shown that the deviations from the expected ratios observed in these cultures are significant and are due to the presence of genes in at least 39% of the third chromosomes encountered in natural populations which produce slight but perceptible reductions of viability in homozygous condition. Finally, a small minority of the wild third chromosomes, probably not much more than 2%, seem to carry genetic factors that improve the viability of the flies, at least under the environmental conditions in which the flies are raised in laboratory experiments.

We may conclude that no less than 54% of the third chromosomes found in natural populations of *Drosophila pseudoobscura* contain recessive genes that are deleterious and only about 2% of the tested chromosomes carry genes favorable for viability. Now, the species *D. pseudoobscura* has five pairs of chromosomes. One of them, the sex determining X-chromosome, is in a somewhat special condition; the others may be expected to be populated with unfavorable viability genes to an extent comparable to that observed in the third chromosome. Indeed, preliminary experiments of Sturtevant (5) suggest that this is the case for the second chromosome. It follows that flies free from hidden unfavorable viability genes must be rare in natural populations; reduction of viability following inbreeding is, consequently, not unexpected. Yet, as stated above, a few of the chromosomes seem to carry superior genes. If an analogous situation obtains not only in wild races of *Drosophila* but in domestic plants and animals as well, the importance of it from the breeder's standpoint requires no comment.

In discussing the genetic procedure used for the detection of the viability genes in *Drosophila* we have, up to now, deliberately refrained from mentioning one of its essential features, which must be carefully thought through if a similar technic is to be developed for corn investigations. The crosses represented schematically in Fig. 1 are designed to obtain individuals known to carry a given type of third chromosome in duplicate, for only under such condition can the recessives borne in this chromosome manifest themselves. It is necessary, therefore, that the chromosome in question be transmitted intact from generation to generation in the whole series of crosses. Yet this chromosome runs the risk of being broken up by crossing-over with other types of third chromosomes. To avoid, or at least to diminish, this risk, the chromosomes containing the gene markers are made to carry inverted sections that suppress most or all crossing-over. A brief explanation of the rôle of inverted sections may be useful here for the sake of those not fully conversant with the intricacies of modern cytogenetics.

Let the usual or normal gene order in a chromosome be represented as *ABCDEFG*; if the portion of the chromosome containing the block of genes from *B* to *E* is inverted, i.e., rotated by 180 degrees, the gene order becomes *AEDCBFG*. In individuals carrying one chromosome with the normal gene order and one with the inverted order, crossing-over can occur in the inverted region provided meiotic pairing takes place. Fig. 2 shows, however, that single crossovers within the inversion give rise to chromosomes deficient for some genes and carrying

be possible through such an analysis to demonstrate, for example, that chromosome 7 of one inbred strain carries a dominant favorable gene (or genes) not found in chromosome 7 of another inbred line, while the latter, on the other hand, may have a group of favorable dominants in chromosome 3 which are not present in chromosome 3 of the first inbred.

Theoretically, it should be possible to find those chromosomes in the different inbred lines that carry the most desirable assemblages of favorable dominant genes for yield or other agronomic characters. Such information might, conceivably, be of considerable assistance to the corn breeder. At any rate, it should provide a more enlightened foundation for the breeding program. Certain results recently obtained in an organism very different from maize, namely, the fly, *Drosophila pseudoobscura*, are of interest in this connection, as pointing towards the working out of such breeding methods (5, 1, 2).

Samples of natural populations of *Drosophila pseudoobscura* were taken in various localities where this species occurs, especially on certain mountain ranges in California and Nevada. Individual flies coming from the same as well as from different samples proved to be scarcely if at all different in appearance from each other. And yet, a tremendous genetic diversity was found concealed behind this apparent external uniformity. The following experimental procedure was employed by Dobzhansky and Queal (2) in these studies. Individual males collected in their habitats were crossed to females homozygous for the third chromosome recessives orange (*or*) and purple (*pr*). These mutant genes serve as markers enabling one to follow the third chromosomes of the wild males in inheritance. Single males were taken from the F_1 generation of each cross and outcrossed to females carrying in one of their third chromosomes the recessives *or*, *pr*, and the dominants Blade (*Bl*) and Scute (*Sc*). In the next generation females and males showing the characters *Bl* and *Sc* but not those of *or* and *pr* were selected and intercrossed. In the offspring, some individuals must be homozygous for *or*, *Bl*, *Sc*, and *pr*; since the gene *Bl* has a lethal effect when homozygous, these individuals die (Fig. 1). Among the survivors, one-third or 33.3%, are homozygous for a third chromosome derived from the wild ancestor and are expected to be normal, or wild-type, in appearance. Two-thirds or 66.7% of the individuals carry one normal third chromosome and one *or Bl Sc pr* chromosome. They will show the characters *Bl* and *Sc*.

The above theoretical expectation is, however, far from always realized in practice. Among 849 crosses of this kind executed by Dobzhansky and Queal (2) nearly 12% produced no wild-type offspring. The only possible explanation of this fact is that about 12% of the cultures studied carried a third chromosome having a recessive lethal gene or genes which produce no visible external effects when heterozygous. Another 3% of the cultures had between 0% and 14% of wild-type flies instead of the expected 33.3%. The third chromosomes involved in such crosses carry recessive semi-lethal genes that reduce the viability of the homozygotes far below normal. The remainder of the cultures contained between 18% and 50% of wild-type individuals. A further analysis, the details of which need not be dis-

A POSSIBLE METHOD FOR LOCATING FAVORABLE GENES IN MAIZE[1]

TH. DOBZHANSKY AND M. M. RHOADES[2]

PRESENT-DAY methods of corn improvement involve the isolation of inbred lines through self-fertilization and selection. These inbred strains are subsequently intercrossed and some, though not all, hybrid combinations are superior in vigor to the open-pollinated varieties from which the inbred lines were derived. Practically all crosses are greatly superior to the vigor of the inbred parents. The theoretical foundations for the increased vigor obtained by these empirical methods have never been completely established. The assumption is that open-pollinated varieties of corn are heterozygous for many pairs of genes, the recessive alleles of which have in general less favorable effects upon viability and vigor than their dominant alleles. Different varieties and different individuals of the same variety may carry different recessive genes.

Under field conditions, cross-pollination rather than self-pollination usually occurs, hence the recessives tend to be suppressed by their dominant alleles. The occurrence of some of the barren and weak plants in a varietal population can however be attributed to the homozygosity of less favorable recessive genes. Self-fertilization permits the manifestation of recessives, while intercrossing of inbred strains restores the hybrid vigor, provided the two inbred lines possess different favorable dominant genes. One inbred line may carry a less favorable recessive *a* and a more favorable dominant gene (or genes) *B* and a second inbred strain may possess dominant *A* and recessive *b*. The hybrid between the two will carry both dominant *A* and *B* and consequently will be superior in vigor to the two parents. It may be further assumed that, on the whole, those hybrid combinations resulting from the combining of inbred strains carrying many different favorable dominant genes will have more vigor than those hybrids from lines combining a small number of different dominants.

Richey and Sprague (4)[3] have presented data which argue strongly for the validity of the dominant favorable gene hypothesis as the cause of hybrid vigor, but they do not exclude the possibility that their data might have resulted, in part at least, from a kind of physiological stimulation caused by bringing together gametes with unlike germ plasms. However that may be, it is reasonable to assume that a method which would permit an exact analysis of the genetic constitution of separate chromosomes might be of practical value as well as having a direct bearing on the correctness of the two possible interpretations of the effects of inbreeding and hybrid vigor given by Richey and Sprague (4). On the dominant favorable gene hypothesis it should

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[1]Joint contribution from the Division of Biology, California Institute of Technology, and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication April 27, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 674.

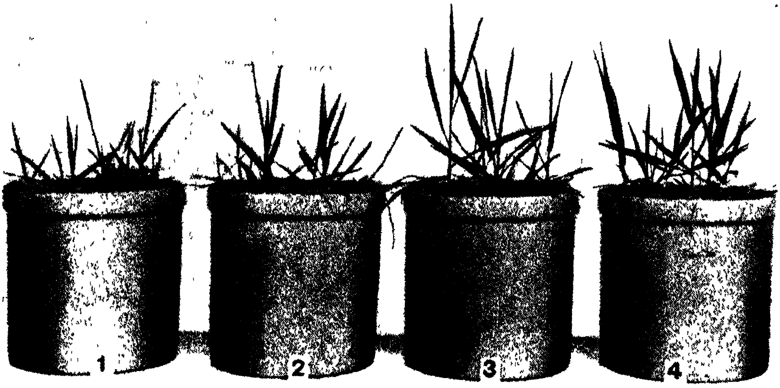

FIG. 1.—Pot 1, no selenium; pot 2, 0.0496 p. p. m. selenium; pot 3, 1.0240 p. p. m. selenium; pot 4, 2 5600 p. p. m. selenium.

work of Levine.[3] A bibliography of 23 references on selenium has been compiled by Willis.[4]

CONCLUSIONS

When Tenmarq wheat was grown in the greenhouse on Derby soil and not allowed full winter dormancy, the following observations were recorded:

1. Light applications of selenium aided early germination.
2. Early growth (fall) was depressed by selenium applications, the degree of depression varying directly with the amount of selenium applied.
3. Applications of selenium of 6 p.p.m. and more killed the wheat. The heavier the application, the earlier death resulted.
4. Applications of selenium up to 2.5 p.p.m. stimulated the spring growth and harvest weight.

[3]LEVINE, V. E. Amer. Jour. Bot., 12:82–90. 1925.
[4]WILLIS, L. G. Bibliography of The Minor Elements. Ed. 2. Chilean Nitrate Educational Bureau.

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EFFECT OF STRAINS OF NODULE BACTERIA AND LIME ON THE RESPONSE OF SOYBEANS TO ARTIFICIAL INOCULATION[1]

CHAS. F. BRISCOE AND W. B. ANDREWS[2]

THE carbohydrate-nitrogen relation in symbiotic nitrogen fixation has been investigated by Wilson (13)[3], Umbreit and Fred (11), and others. The greatest fixation of elemental nitrogen takes place where the assimilation of CO_2 and nitrogen are in balance which gives a medium carbohydrate-low nitrogen plant. Wilson suggests that strains of organisms may vary in response to a given carbohydrate-nitrogen relation in the plant. If they do, inoculation tests conducted in the greenhouse and at different seasons of the year may not be applicable in the field.

Baldwin and Hofer (2) found that certain strains of bacteria produced nodules only when there was a high carbohydrate-nitrogen relation (spring) in the plant, while one strain produced nodules on both the winter and spring plantings. They also found that the response of strains of organisms to the carbohydrate-nitrogen relation was modified by cultivation on media containing different forms of nitrogen.

Orcutt and Fred (8) found that partial shading of soybeans grown in nitrogen-free sand caused them to fix atmospheric nitrogen where they failed to fix nitrogen in the sunlight of early summer. Variations in the light intensity and rainfall in different sections of the country may produce different carbohydrate-nitrogen relations in plants. If different carbohydrate-nitrogen relations exist in one species of plants grown in different sections of the country, the work of Baldwin and Hofer (2) indicates that variations in the effectivenss of strains of Rhizobia may exist when used under the different climatic conditions.

Variations in the inoculation of varieties of soybeans by a given culture of Rhizobia have been pointed out by Voores (14), who found that the Haberlandt failed to produce nodules under the same inoculation conditions that Mikado, Peking, Tarheel Black, Brown, and Auburn varieties produced an abundance of nodules. Similarly, Morse (7) found that the Acme and Tokio varieties failed to produce nodules where Mammoth produced an abundance of nodules.

[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication April 29, 1938.

[2]Bacteriologist and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 718.

On the basis of the research work reported previous to 1932, Fred, Baldwin and McCoy (4) placed cowpeas and soybeans in different cross inoculation groups. Soybeans have been observed to produce nodules in many cases where they have not been grown previously. Leonard (5), Walker (12), Carroll (3), Reed and Baldwin (9), and Sears and Carroll (10) have found that cross inoculation takes place between the cowpea and the soybean groups. In general, soybean strains of Rhizobia produce good nodulation on cowpeas but only a few strains of cowpea Rhizobia produce nodules on soybeans.

Variations in the effectiveness of strains of nodule bacteria have been reported by many investigators, including Fred, Baldwin, and McCoy (4). Recently, McCalla (6) found that abnormal cultures of nodule bacteria may be produced from normal cultures when grown on a culture medium lacking in calcium. He concludes that, "In the presence of an ample supply of calcium, normal legume bacteria remained normal and abnormal or so-called variant forms became normal. All these, after growth with ample calcium, gave good nodulation on plants supplied with calcium. In the absence of calcium, the normal legume bacteria became abnormal and the abnormal forms remained abnormal, both failed to nodulate the host plant." The pH of the culture medium lacking calcium was maintained by the addition of barium.

That strains of nodule bacteria vary in their lime requirement was shown by Alway and Ness (1), who found that pure cultures of alfalfa nodule bacteria required more lime in the establishment of stands of alfalfa than do soil cultures

The purpose of this paper is to present preliminary data on (a) variations in the response of varieties of soybeans to strains of nodule bacteria, (b) the response of one variety of soybeans grown in Mississippi to strains of Rhizobia from other sections of the country, (c) the response of strains of Rhizobia to lime, and (d) the inoculation of soybeans by cowpea Rhizobia.

EXPERIMENTAL

The response of Mammoth Yellow and Laredo soybeans to lime and to a good and a poor strain of nodule bacteria was determined in the field on Lufkin clay, using 1/60 acre plats with four rows 3½ feet apart. All plats received 600 pounds of 0-8-4 fertilizer per acre and the limed plats received 2 tons of ground limestone per acre. The air-dry yields are reported in Table 1. The soybeans were harvested in the full pod stage Although the Laredo lost more leaves than the Mammoth Yellow, the results are comparable.

Sixteen strains of good soybean nodule bacteria were obtained from various agricultural experiment stations, as follows: Iowa, 3; Florida, 2; U. S. Dept. of Agriculture, 7; and Mississippi, 3. In addition one good strain of cowpea nodule bacteria was obtained from New York and one from Wisconsin. These cultures were used to inoculate Mammoth Yellow soybeans on limed and unlimed Lufkin clay soil. The pH of the untreated soil was 4.40. All plats received 600 pounds of 0-8-4 fertilizer per acre in the drill and the limed plats received 400 pounds of dolomite per acre in the drill. The plats were one row, 3½ feet wide, and 1/400 acre in size. There were 6 plats of each treatment except the check which had 18 plats. The soybeans were cultivated to keep down the weeds.

TABLE 1.—*The effect of the variety of soybean and lime on the effectiveness of strain of root nodule bacteria.*

Variety	Kind of nodule bacteria	Yield in pounds per acre			
		Limed	Unlimed	Increase due to lime	Odds
Mammoth Yellow	Poor	3,440	1,800	1,640	18
Laredo	Poor	1,560	1,120	440	8
Mammoth Yellow	Good	4,310	3,000	1,310	81
Laredo	Good	3,020	1,020	2,000	25
Mammoth Yellow	None	1,990	1,130	860	272
Laredo	None	1,670	1,130	540	265
	Increase Over no Inoculation*				
Mammoth Yellow	Poor	1,400	720	—	—
Odds		15	88	—	—
Laredo	Poor	-40	60	—	—
Odds		3	9	—	—
Mammoth Yellow	Good	2,213	1,693	—	—
Odds		80	106	—	—
Laredo	Good	1,293	-213	—	—
Odds		65	72	—	—

*These increases are not derived directly from the above data because, where possible, advantage was taken of an increase in number of plats

The soybeans were harvested in the small pod stage and green weights were obtained and converted to air-dry weights per acre. Total nitrogen determinations were made on the air-dry hay according to the methods of official agricultural chemists. The data are reported in Tables 2 and 3.

Previous to the field testing the strains of bacteria were grown in the laboratory on low-nitrogen media containing ample calcium. The soybean seed were measured out for each row and an excess of the different cultures was applied after which the seed were covered. Very few nodules occurred on the unlimed checks; however, the limed checks produced quite a few nodules.

In the first experiment reported Student's odds were calculated. In the other experiment standard errors of the increases were calculated from paired differences.

RESULTS AND DISCUSSION

INFLUENCE OF VARIETY ON THE EFFECTIVENESS OF STRAINS OF NODULE BACTERIA

The good and the poor strains of soybean nodule bacteria used in the experiment reported in Table 1 were obtained from the University of Wisconsin. The good strain has given uniformly good results. The poor strain has been used in experiments in the greenhouse where it has given uniformly poor results. On the unlimed soil the Laredo showed no response to either the good or the poor strain of

TABLE 2.—*The response of soybeans to strains of root nodule bacteria and lime.*

Culture		Unlimed soil			Limed soil		
No.	Source	Increase over check, pounds air-dry hay per acre	Nitrogen %	Increase over check, pounds nitrogen per acre	Increase over check, pounds air-dry hay per acre	Nitrogen %	Increase over check, pounds nitrogen per acre
512	Laredo soybean, Miss.	877±297*	1.89±0.066	24.1±5.73	520±303	2.05±0.079	19.9± 6.27
522	Pimpu soybean, Iowa	760±365	1.77±0.097	18.5±7.87	404±252	1.89±0.056	12.3± 7.20
523	Soysota soybean, Iowa	529±233	1.48±0.153	8.7±8.67	296±176	1.61±0.028	4.1± 5.60
524	Midwest soybean, Va.	39±340	1.42±0.079	1.5±6.67	337±260	1.63±0.097	3.7± 6.00
525	Virginia soybean, Va.	371±411	1.52±0.140	5.5±8.13	424±243	1.80±0.103	9.5± 7.47
526	Guelph soybean, Va.	237±361	1.45±0.103	3.9±6.27	603±209	1.68±0.113	8.7± 7.33
527	Tokio soybean, Va.	587±437	1.63±0.153	12.0±9.73	843±239	1.95±0.088	23.2± 6.13
528	Haberlandt soybean, D. C.	157±245	1.44±0.121	0.9±4.80	191±263	1.73±0.047	4.8± 6.13
529	Laredo soybean, Va.	183±375	1.41±0.080	0.1±1 07	53±327	1.67±0.241	1.5± 7.20
531	Tarheel soybean, Va.	523±363	1.75±0.166	16.4±8.13	509±279	1.83±0.155	0.1± 7.73
532	Wilson soybean, D. C.	524±355	1.60±0.062	10.1±6.67	477±288	1.75±0.114	9.2± 5.07
533	Itosan soybean, Va.	323±337	1.39±0.118	3.2±7.33	183±269	1.69±0.117	2.8± 4.40
534	Soybean, Florida	423±341	1.50±0.137	7.2±5.33	237±308	1.68±0.110	6.1± 7.47
536	Soybean, Florida	687±379	1.78±0.105	17.5±7.87	564±282	1.81±0.068	13.5± 7.20
537	Mamredo soybean, Miss.	611±298	1.84±0.134	18.3±8.53	404±147	2.02±0.130	18.4± 4.53
541	Mamredo soybean, Miss.	271±346	1.71±0.138	8.8±6.53	120±104	1.73±0.178	6.1± 4.40
CP15	Cowpea, New York	673±333	1.71±0.227	17.1±6.93	449±154	1.81±0.178	11.9± 4.53
CP24	Cowpea, Wis.	313±315	1.45±0.119	3.7±4.80	183±184	1.89±0.093	9.7±20.4
Check		1920±401	1.47±0.100	29.6±7.47	2629±389	1.56±0.142	45.3±10.93

*Standard error.

nodule bacteria, whereas the yield of the Mammoth Yellow was increased 720 pounds and 1,693 pounds per acre by the poor and the good strain, respectively. These increases are statistically significant. On the limed soil the Laredo was not benefited by the poor strain and the good strain increased its yield 1,293 pounds per acre, while the yield of the Mammoth Yellow was increased 1,400 pounds and 2,213 pounds per acre by the poor and the good strain, respectively. The former increase is not statistically significant; the latter is.

TABLE 3.—*The effect of lime on the yield, nitrogen content, and total nitrogen where different strains of root nodule were applied.*

Culture		Increase due to lime		
No.	Source	Pounds air-dry hay per acre	Nitrogen %	Total nitrogen, pounds per acre
512	Laredo soybean, Miss.	444±278*	0.18±0.104	11.5±6.13
522	Pimpu soybean, Iowa	356±287	0.12±0.083	9.5±6.67
523	Soysota soybean, Iowa	477±232	0.22±0.102	12.5±2.27
524	Midwest soybean, Va.	1013±355	0.21±0.120	20.9±6.53
525	Virginia soybean, Va.	764±277	0.28±0.167	19.6±7.73
526	Guelph soybean, Va.	1164±242	0.23±0.170	22.7±4.40
527	Tokio soybean, Va.	967±255	0.32±0.166	26.9±7.87
528	Haberlandt soybean, D. C.	744±305	0.28±0.070	19.6±7.47
529	Laredo soybean, Va.	583±217	0.26±0.119	17.7±6.67
531	Tarheel soybean, Va.	697±245	0.01±0.315	12.5±11.60
532	Wilson soybean, D. C.	664±187	0.14±0.149	14.8±5.73
533	Itosan soybean, Va.	571±163	0.31±0 143	18.8±5.33
534	Soybean, Florida	517±225	0.19±0.119	14.8±4.53
536	Soybean, Florida	589±165	0.03±0.106	11.6±5.33
537	Mamredo soybean, Miss.	504±240	0.18±0.207	15.9±10.80
541	Mamredo soybean, Miss.	560±282	0.02±0.141	13.1±9.20
CP15	Cowpea, New York	487±202	0.06±0.220	9.7±9.33
CP24	Cowpea, Wis.	651±140	0.44±0.044	21.7±4.13
Check	. . . .	688±165	0.15±0.082	15.7±3.40

*Standard error.

The response of Laredo to the poor strain of nodule bacteria is in agreement with the results obtained in greenhouse experiments at Mississippi Experiment Station. The response of Mammoth Yellow to the poor strain is contrary to that of Laredo. The difference in the response of Laredo and Mammoth Yellow to the good and poor strains of bacteria is in agreement with the data of Voores (14) and Morse (7), who found that certain varieties of soybeans failed to produce nodules where other varieties produced an abundance of nodules.

RESPONSE OF SOYBEANS TO GOOD STRAINS OF NODULE BACTERIA

Unlimed soil.—The 16 strains of soybean nodule bacteria used in this experiment were obtained from different sections of the United States. On the unlimed soil (Table 2) there were only four strains of nodule bacteria which produced yields significantly greater than the check. They were Nos. 512, 522, 523, and 537. Out of the 16 strains of soybean nodule bacteria used, the nitrogen content of the soybeans

was lower, but not significantly lower, than the check where five of them were used. Seven strains increased the nitrogen content slightly, but not significantly. Only four strains increased the nitrogen content of the soybeans significantly. They are Nos. 512, 522, 536, and 537. Three of the four strains which increased the yield significantly also increased the nitrogen content significantly. Significance as used in this paper is based upon the difference being twice its standard error.

The effect of the inoculation can be interpreted more easily from the combination of the nitrogen content and the yield, which gives the total nitrogen in the soybeans. The data in Table 2 show that 5 of the 16 soybean strains produced increases in total nitrogen which were significantly greater than the total nitrogen of the check. Strain No. 512 had 24.1 ± 5.73 pounds of total nitrogen more than the check. The nitrogen fixed by this strain was significantly greater than that fixed by nine other strains.

Limed soil.—On the limed soil 4 of the 16 strains of soybean nodule bacteria increased the yield significantly. The other 12 strains increased the yield from 53 pounds to 520 pounds per acre and significance was approached by some of them. Four strains increased the nitrogen content of the soybeans significantly. Strains Nos 527 and 537 increased both the yield and nitrogen content significantly.

Strain No. 537 was the only strain which increased both the yield and the nitrogen content of the soybeans significantly on both the limed and the unlimed soil. This strain was isolated from Mamredo soybeans in Mississippi. Strains Nos 512 and 522 increased the yield and nitrogen content of the soybeans on the unlimed soil significantly and the nitrogent content on the limed soil. Strain No. 512 was isolated from Laredo soybeans in Mississippi; No. 522 from Pimpu soybeans in Iowa. Strain No 527 was one of the best strains on the limed soil. It was isolated from Tokio in Virginia.

Three of the 16 strains used in this test were isolated in Mississippi and this was the first field test in which they have been used. The other 13 were strains which had proved their value in other states. The best strain in the test was Mississippi No. 537. Mississippi strain No. 512 was in the second best group with Iowa No. 522. Mississippi strain No. 541 was one of the poorer strains. These data indicate that good strains of nodule bacteria isolated locally may be more efficient than good strains from other climates.

Even though there were six replications of each treatment, the standard errors were very large.

On the limed soil 4 of the 16 strains produced increases in nitrogen content which are significantly greater than the check. The total nitrogen fixed by strain No. 527 is significantly greater than that fixed by 9 of the other 15 strains used in the test.

RESPONSE OF SOYBEANS TO LIME WHEN INOCULATED WITH DIFFERENT STRAINS OF NODULE BACTERIA

Alway and Ness (1) found that pure cultures of nodule bacteria are more sensitive to a deficiency of calcium than are soil cultures when used to inoculate alfalfa. The data in Table 3 show that lime

increased the yield of the check 688±165 pounds per acre. Lime increased the yield of soybeans where the different strains of bacteria were used from 356±287 to 1,164±242 pounds per acre. However, in no case was there an increase which was significantly greater than the increase in yield obtained without inoculation.

The increases in nitrogen content due to the application of lime are also reported in Table 3. The nitrogen content of the check was increased 0.15±0.082% by the application of lime. The nitrogen content of the soybeans receiving cowpea No. 24 bacteria was increased 0.44±0.044% by the addition of lime. The cowpea No. 24 strain of nodule bacteria showed a greater response to lime than any strain of bacteria used in the test. It should be borne in mind that on the unlimed soil this strain did not increase the nitrogen content of the soybeans, whereas many of the other strains produced good increases in the nitrogen content on the unlimed soil. The increase in nitrogen content due to the application of lime where this cowpea No. 24 was used, was significantly greater than the increase obtained where strains Nos. 541, 536, 535, 522, 512, and 502 were used.

The increase in total nitrogen due to the application of lime was greater where strain No. 527 was used than where any other strain was used. The increases in total nitrogen varied from 9.5±6.67 to 26.9±7.87. The differences between the strains are not statistically significant.

The data in Table 1 show that lime increased the yield of Mammoth Yellow soybeans 860, 1,640, and 1,310 pounds per acre where none, poor, and good nodule bacteria were used, respectively. The corresponding increases where Laredo was grown were 540, 440, and 2,000 pounds per acre, respectively.

INOCULATION OF SOYBEANS BY COWPEA NODULE BACTERIA

Leonard (5) reported that good results were obtained when a soybean strain of Rhizobia was used to inoculate both soybeans and cowpeas. The results when a cowpea strain was used were quite different. The cowpea strain usually failed to produce nodules on soybeans. Other investigators report similar results.

The cowpea strains of nodule bacteria used in this experiment were obtained from the Wisconsin and the New York Agricultural Experiment Stations. The cowpea No. 15 strain from New York increased the yield of Mammoth Yellow soybeans (Table 2) 673±333 pounds and 449±154 pounds per acre and the nitrogen content from 1.47±0.100% to 1.71±0.227% and from 1.56±0.142% to 1.81±0.178% on unlimed and limed soil, respectively. The increases in yield are statistically significant; the increases in nitrogen content are not. The cowpea strain from Wisconsin increased the nitrogen content significantly on the limed soil; however, the increases in yield obtained on both the limed and the unlimed soil were not significant where this strain was applied and the nitrogen content of the soybeans on the unlimed soil was not increased by this strain.

If the data presented by Leonard (5) are combined with those presented in this paper, it is evident that good inoculation of soybeans or

cowpeas may be obtained by a suitable strain from either the cowpea or the soybean cross inoculation group. If these data are combined with those presented above which show that different varieties of soybeans respond differently to different strains of nodule bacteria, the evidence indicates that differences between the soybean and the cowpea cross inoculation groups are probably similar to those existing within varieties of soybeans. The evidence presented raises the question, Is the separation of soybeans and cowpeas into different cross-inoculation groups justified? But it is evident that major emphasis should be placed upon additional experiments to determine the effectiveness of strains for different varieties of soybeans and species of the cowpea group rather than on an effort to combine the groups.

SUMMARY AND CONCLUSIONS

The response of Mammoth Yellow and Laredo soybeans to a good and to a poor strain of soybean nodule bacteria was determined in the field on limed and unlimed soil. Sixteen strains of good soybean nodule bacteria and two strains of cowpea root nodule bacteria were obtained from different sections of the country and used to inoculate Mammoth Yellow soybeans in the field on limed and unlimed soil. There were six replications of each treatment in the latter test. The standard error of the data obtained was quite large even though an apparently fairly uniform soil was used. The work is to be repeated to check the conclusions more closely. From the data presented the following conclusions are drawn:

1. Variations in the response of Mammoth Yellow and Laredo soybeans to strains of nodule bacteria are probably as great as differences between the soybean and the cowpea cross inoculation group.
2. Emphasis should be placed upon the isolation of strains of nodule bacteria best suited to the different varieties of soybeans and species of the cowpea group rather than attempting to place soybeans in the cowpea cross inoculation groups.
3. There is an indication that strains of soybean nodule bacteria isolated locally are more efficient than strains obtained from different climates.
4. The lime requirement of strains of soybean Rhizobia varies considerably.

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"WEAK NECK" IN SORGHUM[1]

A. F. Swanson[2]

DWARF varieties of grain sorghum adapted to combine harvesting have become very popular within the past eight years in regions where the crop is extensively grown. Varieties suited for this purpose must possess strong stalks and peduncles to prevent the heads from breaking over, because the crop often has to stand in the field until late fall in order to dry sufficiently for satisfactory combining and safe storage.

One of the difficulties experienced in selecting dwarf grain sorghums adapted to combine harvesting has been to find varieties with peduncles strong enough to maintain heads in an upright position. The breaking over of heads has been assumed by most sorghum workers to be due to the combined effects of wind, moisture, and gravity, accentuated by a greater leverage in varieties having long peduncles. It has also been thought that the translocation of more carbohydrates from the stalks into the heads of certain dry-stalked types might be a differentiating factor in decreasing resistance to lodging.

Although all of the above suggested factors may be operative, the chief factor influencing the percentage of broken over heads is now believed to be due to a specific malady in the peduncles Whether the causal factor is an organism or a non-parasitic breakdown of the tissues remains to be determined. This apparent diseased condition seems to interfere with the translocation of organic material to the grain as evidenced by the poorly filled heads associated with weakened peduncles. When the weakened plants are subjected to the elements, many of the heads are likely to be broken over This condition was very apparent at Hays, Kans., in the fall of 1937 when the examination of hundreds of individual plants showed that weak peduncles were nearly always associated with badly disintegrated tissues.

Many data have been published on broken and weak corn stalks, but these may be related only indirectly to the problem here discussed. Pammel, King, and Seal[3] in 1916 described a Fusarium disease of certain sorghum varieties as follows:

"When the Fusarium attacks sorghum, the canes break at the joints, sometimes beginning at the first joint; more frequently most of the joints are attacked. These readily break off. The roots are

[1]Results of investigation conducted cooperatively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans., at the Fort Hays Branch Experiment Station, Hays Kans. Contribution No. 26, Fort Hays Branch Experiment Station.
The term "weak neck" was suggested by Prof. L. E. Melchers, Botany Department, Kansas State College of Agriculture and Applied Science, as descriptive of the diseased condition associated with broken peduncle and lodged heads in sorghum. Acknowledgment is gratefully made to Prof. L. E. Melchers and Dr. J. H. Parker for assistance in preparing this paper. Received for publication May 12, 1938.

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[3]Pammel, L. H , King, D. M., and Seal, J. L. Studies on a Fusarium Disease of corn and sorghum. Iowa Agr. Exp. Sta. Res. Bul. 33, 1916.

apparently not so seriously affected as in corn, as the plants are removed with difficulty from the ground. . . . We found in many cases that the plants affected are enfeebled by the disease and that the heads are small and not fully filled.

"The diseased heads show the fungus in the seed. Where the fungus occurs at the nodes the spores are found in great abundance on the surface of the stalk. The mass is whitish with a slight purplish tinge. The interior of the cane is disintegrated and purplish or brownish in color, with an abundance of the mycelium. The leaf sheaths give sufficient protection from drying out so that spores are produced there in great numbers There is little decay beyond the nodes, most of the injury being confined to within half an inch of the node."

Some of the symptoms noted by these Iowa workers were apparent in the sorghum plants examined at Hays. The chief difference at Hays is that the disintegration of the tissue was confined almost entirely to the peduncle.

SYMPTOMS OF "WEAK NECK" OF SORGHUM

One of the symptoms of "weak neck" of sorghum is the disintegration of the tissues of the peduncle, associated with and indicated by a blackened or gray discoloration. This discoloration may be found in different degrees of intensity throughout the entire length of the peduncle, or in localized areas. The most vulnerable point of injury is at the junction of the peduncle and upper node of the stalk. In the more severe cases the affected areas may extend downward into the first or second internode. Sometimes the tissue disintegration at the base of the head is so extensive that the head will break off readily with the lightest mechanical shock. More commonly the disintegration is only slight and localized between the extremities of the peduncle. This generally causes little damage.

A second symptom is the large proportion of heads broken over where the peduncle joins the upper node of the stalk (Fig. 1). The tissues where the head is broken over are always badly disintegrated.

A third symptom is the presence of poorly developed, scrawny heads containing light-weight, lusterless seed This is especially noticeable when a plant is affected early in its development. The symptoms are more marked in the earlier planted sorghums than in late plantings and more severe in main stalks than in tillers. Susceptible strains grown in the greenhouse at Hays during the winter of 1937–38 gave poorly developed plants with a high percentage of sterility, indicating that "weak neck" may be seed-borne. On the other hand, selections from varieties known to be resistant to the malady grew in the greenhouse with normal vigor.

Sorghum "weak neck" is frequently associated with the presence of aphids and more or less disintegration of the peduncle has been observed where aphids are abundant in the top sheaths. The reddening of the leaves and peduncle also seems to indicate that the plant tissue has been punctured. Whether or not aphids act as a vector of bacterial or fungus infection has not been determined.

FIG. 1.—"Weak neck," a sorghum disease which weakens the peduncle and causes the head to break over.

It has been observed that in certain varieties that appear to be susceptible to the disease, complete breaking-over does not necessarily follow unless aggravated by high wind and rain. Where the peduncle has reached the more acute stages of disintegration, a light jar of a standing sorghum head will break it over. The peduncle of a healthy sorghum plant ripens with a bright golden color and is capable of withstanding heavy blows or high winds for a considerable period after the grain is fully ripe. Breaks in a healthy peduncle tend to be clean rather than ragged and disintegrated. If a diseased peduncle is split with a knife, the darkened pit of the peduncle, as well as the gray discoloration of the cortical tissues, is evident.

INHERITANCE OF "WEAK NECK"

All true sorgos appear to be highly resistant to "weak neck", and of the grain sorghums, strains of Blackhull kafir and a new variety known as Club are among the most resistant. Milo seemingly is susceptible to "weak neck," but because of the consequent reduced leverage of short peduncles, the breaking over of the heads is rather infrequent; consequently, the malady may be present to a greater degree in milo than is likely to be recognized.

Hybrids between milo and kafir, and particularly those with long peduncles, appear to be especially susceptible. Observations of hundreds of plants in the hybrids of Club × Day and Wheatland Backcross × Club, Day, and Colby milo indicated high susceptibility. All of these sorghums are derived from crosses in which Dwarf yellow milo was one of the parents. It was estimated that 73% of all the plants in 98 late-generation progeny rows of the Club × Day cross in the early planting and 53% in a later planting were diseased. Other observations have shown that the disease is more prevalent in early-planted than in late-planted sorghums, although certain strains have shown an opposite reaction. In the Club × Day progenies the yellow-seeded segregates as a rule showed much higher susceptibility than did the white-seeded segregates that resembled the Club parent. A hopeful view of the situation is gleaned from the fact that occasionally immune plants were found in susceptible lines. Entire rows also were found with low susceptibility but nearly always among the white-seeded Club-like segregates.

Almost complete resistance to "weak neck" was noted in the F_3 progenies of the cross Leoti Red sorgo × Club. A number of dwarf plants with grain-producing possibilities occurred in this cross. Aphids were not abundant on plants of this cross. Since both the Club and Leoti Red have given evidence of resistance when used as parents in crosses, there is hope that "weak neck" can be controlled by plant breeding methods.

Wheatland, a grain sorghum well suited to combine harvesting, was found to be relatively resistant to weak neck. This is probably a factor accounting for the resistance to lodging of this variety, and for its consequent popularity.

"WEAK NECK" NOT ASSOCIATED WITH PYTHIUM ROOT ROT IN SORGHUM

Pythium root rot[4], attacks the roots and crowns of certain varieties of sorghum, causing early death in severe cases. Milo and most milo derivatives are highly susceptible to this disease. All roots and crowns of plants affected with "weak neck" which have been examined were found to be clean and healthy and showed no symptoms of Pythium root rot. Certain selections known to be resistant to Pythium root rot were among those also resistant to the "weak neck" disease.

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[4]Bowman, D. H., Martin, J. H., Melchers, L. E., and Parker, John H. Inheritance of resistance to pythium root rot in sorghum. Jour. Agr. Res., 55:105–115. 1937.

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"WEAK NECK" NOT YET A FARM PROBLEM

While weak peduncles and lodged heads often have been seen in the plant breeding nurseries at Hays and at other stations, the presence of this diseased condition has not been observed generally on farms. The reason for this may be that many of the varieties of sorghum grown on farms have shown high resistance to "weak neck." Wheatland, the leading sorghum grown for combine harvesting, is relatively resistant to "weak neck". However, the distribution of dwarf types of sorghum suited to combine harvesting but susceptible to "weak neck" may lead to a serious farm problem unless plant breeders take the necessary precautions to avert such a condition.

SUMMARY

Dwarf varieties of sorghum adapted to combine harvesting must have sturdy stalks and peduncles to prevent the heads from breaking over.

Many selections, particularly from milo-kafir crosses, have shown high tendency for the production of weak peduncles. The term "weak neck" has been designated to describe this condition. The cause of the malady has not yet been determined.

The affected tissues become disintegrated and so weakened that the heads break over. The break occurs most frequently at the base of the peduncle.

The sorgos and strains of Blackhull kafir show high resistance to "weak neck," while the milo and milo derivatives having milo characteristics often show high susceptibility.

"Weak neck" is not yet of wide occurrence on farms because the varieties grown are for the most part resistant to the disease. The distribution of varieties susceptible to "weak neck," however, will increase the prevalence of the disease.

Late planting on a well-prepared seedbed tends to reduce the prevalence of "weak neck" in susceptible varieties. More complete control may be expected from plant breeding methods.

HYDROCYANIC ACID CONTENT OF DIFFERENT PARTS OF THE SORGHUM PLANT[1]

J. H. Martin, James F. Couch, and Reinhold R. Briese[2]

THE highly toxic nature of hydrocyanic acid liberated from nitrile-glucosides in certain plants, including sorghum (*Sorghum vulgare* Pers.), and the extensive outbreaks of poisoning among domestic animals resulting from grazing on these plants, are of extreme interest both to animal toxicologists and livestock owners. Since poisoning may depend upon the part of these plants eaten by animals, as well as upon numerous other factors, it is important to know how the potential hydrocyanic acid varies in different parts of the plant. This distribution of hydrocyanic acid is of interest also to agronomists and plant physiologists. The origin, rôle, and fate of these nitrile-glucosides in the plant economy are not clearly understood, but they probably are important intermediate compounds in the process by which inorganic nitrogen is converted into protein. Data concerning the relative proportions of the nitrile-glucosides in the various tissues should be of considerable value in solving problems of plant metabolism.

REVIEW OF LITERATURE

Several investigators have published data on the relative quantities of hydrocyanic acid obtained from leaves, stalks, roots, heads, and other tissues of sorghum and other plants. These data show that in different genera there is a variation in the utilization by the plant of hydrocyanic acid or the glucosides that yield it on hydrolysis. The cyanogenetic compounds appear to be synthesized in the leaves and, in some genera, they are translocated to other parts of the plant, including the bark, pith, roots, and seeds.

Willaman and West (12)[3] reported that stalks of feterita sorghum were higher in HCN than the leaves before the plants were 47 days old, after which they were lower, and the stalks contained almost no HCN after 67 days. In Orange sorgo the stalks were higher than the leaves in HCN at the age of 25 days, but the HCN had disappeared from the stalks at the age of 43 days. The same authors later reported (13) that the distribution of hydrocyanic acid in the leaves and stalks was variable in Early Amber sorgo and another variety designated as "Southern cane." Specimens of these varieties grown in Utah contained more hydrocyanic acid in the stalks than in the leaves of young plants but more in the leaves than in the stalks of older plants.

Ghosh (5), working in India, reported 1.5 to 7 times as much hydrocyanic acid in leaves of sorghum (variety and age of plant not stated) as in the stalks.

Swanson (8) found that the leaves of Sudan grass contained much more potential hydrocyanic acid than the stems. From three samples he obtained 33.5, 16.5, and 33 mg of HCN per hundred grams from the leaves and 2.5 mg, traces, and none from the corresponding stems.

[1]Cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, and the Pathological Division, Bureau of Animal Industry, U. S. Dept. of Agriculture. Received for publication May 13, 1938.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, and Chemist and Junior Chemist, Pathological Division, Bureau of Animal Industry, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 733.

Pinckney (7) found more hydrocyanic acid in the leaves than in the stems of an unspecified variety of sorghum.

Acharya (1) in India reported the following mg of hydrocyanic acid per 100 grams of tissue from parts of stunted sorghum plants: Leaves, 13.8; stems, 4.9; and roots, 10.0. He found more HCN in the branches than in the main stem.

Similar relationships have been reported for other cyanogenetic plants. Treub (9) stated that Greshoff found in dried material of *Pangium edule* the following quantities of hydrocyanic acid per 100 grams of tissue: Stems, 1,098 mg; leaves, 679 mg; and petioles, 357 mg; and "large quantities" in the roots. Van Itallie (10) found much more hydrocyanic acid in the leaves than in the stems of *Thalictrum aquilegifolium*. Guignard (6) grew eight varieties of lima beans in his garden at Paris and determined the hydrocyanic acid in the leaves and seeds of each variety. He found that in three varieties the leaves contained two to three times as much as the seeds but in the other five varieties the relationship was reversed and the seeds yielded two to six times as much as the leaves. Guignard recognized that the plants were grown outside their natural habitat and that these relationships may be different in plants grown under conditions more suitable to their development.

The distribution of HCN in certain other grasses also has been investigated. Alsberg and Black (2) found the following quantities of HCN in dried *Panicularia nervata:* Seeds, 32.5 mg per 100 grams of tissue; roots, 32.5 mg; stems, 41.6 mg; and in the entire plant 55.5 mg HCN per 100 grams of tissue. Viehoever, Johns, and Alsberg (11) reported hydrocyanic acid in *Tridens flavus* as follows: Inflorescence stripped of flowers, 3.7 mg; stems, 3 mg; green leaves, 1.7 mg per 100 grams of tissue; dead yellow leaves, none; roots, trace.

Beath, Draize, and Eppson (3) found that more hydrocyanic acid was developed from leaves than from seeds, seed stalks, and flower stalks of arrow grass, the total hydrocyanic acid being distributed as follows: Leaves, 65%; stems, 20%; and seeds, 15%.

While most of the figures given above are undoubtedly in error because the methods of analysis used are now known to be inaccurate and because of unrecognized sources of loss during the actual analyses, they may still be accepted as having considerable value for comparing relative quantities of hydrocyanic acid obtained from different parts of the same specimens of plants analyzed under the same conditions. More detailed information is desirable, however, especially concerning a larger number of varieties and concerning plants grown under different conditions and in different seasons.

MATERIAL AND METHODS

As a part of a general study of the effect of variety and environment upon HCN development in sorghums, a number of analyses were made during the summer of 1936 to obtain further information upon the HCN content of various parts of the sorghum plant. Samples of fresh plants were collected at Arlington Farm, Arlington, Va., near Washington, D. C., and were analyzed immediately for HCN content. A larger number of samples was collected in the Great Plains area at three field stations of the Division of Dry Land Agriculture, Bureau of Plant Industry, through the courtesy of B. F. Barnes, Dalhart, Tex., D. R. Burnham, Tucumcari, N. Mex., and J. J. Curtis, Akron, Colo., who grew the crop, took the plant samples, weighed 100-gram samples of the green tissues immediately, placed them in pint fruit jars, and then filled the jars with 15% alcohol

to preserve the material. The plants when sampled were two months old or older and the main stalks had reached at least the boot stage. The samples were shipped to the laboratory at Washington, D. C., and analyzed as soon as possible after arrival, the periods between collection and analysis being 7 to 14 days.

It has been shown by Briese and Couch (4) that 15% alcohol will preserve green sorghum samples for two to three weeks sufficiently well for ordinary analytical purposes. However, it is now known that this solution cannot be depended upon to develop and preserve the entire amount of hydrocyanic acid which a plant is capable of producing. The determinations from the preserved samples in the 1936 series may be, and probably are, somewhat lower than the actual potential quantities in the plants. This possible discrepancy would require that they be discarded were it not for the fact that they have considerable value for comparative purposes.

In 1937, similar experiments were made with fresh sorghum grown at the same stations. The technic used was the same as in 1936 except that the samples were preserved in mercuric chloride solution containing 1 gram of the salt per 100 grams of sample. The samples were allowed to stand in the laboratory until one to two months had elapsed after collection to allow cyanogenesis to become practically complete, and were then analyzed. Experience with this method has shown that for periods longer than two months the full quantity of HCN can be retained in the samples and that frequently the quantities obtained are higher, and the results therefore more representative, than those obtained by immediate analysis without the use of preservatives.

The samples were analyzed in accordance with Denigès modification of the Liebig titration method described, together with the method of preservation, by Briese and Couch (4). The data show the HCN content on a green weight basis because moisture determinations were not made on all samples in 1936.

EXPERIMENTAL RESULTS

Table 1 contains the data obtained in 1936 from plants grown at Tucumcari, N. Mex., and Akron, Colo., showing comparisons of HCN in leaves, stems, heads, sheaths, and suckers. The duplicate specimens of Atlas, Kansas Orange, and Black Amber sorgos of the September 5 collection at Akron were from portions of the plats where moisture conditions were different. The first set of samples listed for each variety was from plants that were stunted and badly wilted, while the plants in the second set were nearly normal in growth and only slightly wilted. The data show the highest HCN content in the leaves with only small quantities in the sheaths, stems, and heads. Suckers (tillers) contained more HCN than the main stalks.

The detailed distribution of HCN in the various parts of the sorghum plant was determined by an experiment in which the heads, peduncles, sheaths, and individual leaves and internodes were analyzed separately. Plants of the variety Leoti Red sorgo planted on June 4, and 13 weeks old, were collected at Dalhart, Tex., on September 4, 1936. The plants were at that time 27 inches high, had headed, and were severely wilted. A bundle of 50 plants of approximately the same size was gathered about 1 p.m. and taken to the laboratory on the grounds where the plants were stripped of their leaves and sheaths and the stalks cut into sections through each node. Duplicate samples

TABLE 1.—*Hydrocyanic acid content of different parts of sorghum plants grown at Tucumcari, N. Mex., or Akron, Colo., in 1936.*

Variety	Date collected	Date analyzed	HCN in mg per 100 grams of green tissue						
			Leaves	Leaves and stems	Leaves and heads	Sheaths	Stems	Suckers	Heads
			Tucumcari, N. Mex.						
Dawn kafir	Aug. 18	Sept. 1	—	17.8	—	—	4.9	—	—
Dwarf hegari	Aug. 18	Sept. 1	—	40.0	—	—	11.9	—	—
Sumac sorgo	Aug. 18	Sept. 1	—	45.9	—	—	4.3	—	—
Atlas sorgo	Aug. 18	Sept. 1	—	41.0	—	—	2.7	—	—
Honey sorgo	Aug. 18	Sept. 1	—	21.1	—	—	3.2	—	—
Kansas Orange sorgo	Aug. 18	Sept. 1	—	14.0	—	—	8.6	—	—
Feterita	Aug. 25	Sept. 3	—	43.5	—	—	6.2	—	—
Dwarf Yellow milo	Aug. 25	Sept. 3	—	31.9	—	—	3.5	—	—
Dawn kafir	Aug. 25	Sept. 3	—	—	—	—	1.1	13.8	—
Texas Blackhull kafir	Aug. 25	Sept. 3	—	—	20.0	—	3.2	—	—
Dwarf hegari	Aug. 25	Sept. 4	40.0	—	—	—	8.6	—	—
Sumac sorgo	Aug. 25	Sept. 4	37.0	—	—	—	3.2	—	—
Atlas sorgo	Aug. 25	Sept. 4	—	13.3	—	—	1.6	—	—
Honey sorgo	Aug. 25	Sept. 4	21.6	—	—	—	1.6	—	—
Kansas Orange sorgo	Aug. 25	Sept. 4	25.4	—	—	—	4.1	—	—
Acme broomcorn	Aug. 25	Sept. 4	—	—	—	—	3.5	12.4	—
			Akron, Colo.						
Sudan grass	Aug. 25	Sept. 4	26.2	—	—	—	5.7	—	—
Sudan grass (tillers)	Aug. 25	Sept. 4	25.4	—	—	—	5.2	—	—
Atlas sorgo	Sept. 5	Sept. 17	27.0	—	—	5.7	2.7	—	7.2
Atlas sorgo	Sept. 5	Sept. 17	29.7	—	—	5.4	3.2	—	8.4
Kansas Orange sorgo	Sept. 5	Sept. 17	50.8	—	—	7.0	4.9	—	8.1
Kansas Orange sorgo	Sept. 5	Sept. 17	52.4	—	—	6.5	—	—	7.6
Black Amber sorgo	Sept. 5	Sept. 17	24.1	—	—	3.2	—	—	2.7
Black Amber sorgo	Sept. 5	Sept. 17	22.7	—	—	3.0	3.2	—	3.0

were then weighed, representing composites of the leaves in each position from the top leaf down to the fifth leaf. The weighing was completed by 2:30 p.m. The number of living leaves on the stalks varied and the lower leaves were so small that the sixth leaves were composited with the seventh and any lower green leaves. Dead leaves were discarded. The internodes from corresponding positions on the different stalks likewise were composited. The second and third internodes from the top were composited because of their short length. On the following day specimens of this variety were collected from the same plat and the whole plant was sampled for analysis. The samples were preserved in 15% alcohol, shipped to Washington, and analyzed on September 11. The results are presented in Table 2 and diagramatically in Fig. 1.

TABLE 2.—*Hydrocyanic acid content in mg per 100 grams of green tissue of different parts of Leoti Red sorgo plants at Dalhart, Tex., in 1936, average of two samples.*

Part of plant	Hydrocyanic acid, mg	Part of plant	Hydrocyanic acid, mg
Leaf 1 (top)	18.6	Peduncle	3.9
Leaf 2	18.3	Internodes 2 and 3	4.6
Leaf 3	14.5	Internode 4	2.8
Leaf 4	12.8	Internode 5	1.7
Leaf 5	9.8	Internode 6	1.6
Leaf 6	7.3	Internode 7	2.9
Upper 3 sheaths	3.6	Internode 8	2.4
Fourth and 5th sheaths	2.8	Internode 9	1.6
Heads	2.1	Entire plant (following morning)	8.4

The figures obtained show the largest yield of HCN from the leaves and in general a progressive diminution in HCN content from the top of the plant to the bottom both in leaves and in stem internodes. The small amount of HCN that was recovered from the heads is to be attributed to the green stems, branches, and glumes included in the samples since the grain was not yet developed and mature grain itself is cyanide-free. Inasmuch as the upper leaves are younger than the lower, the figures indicate an accumulation of nitrile-glucoside in the more actively growing parts of the plant thus conforming with the common observation that the HCN content of sorghum plants decreases with age.

A similar set of samples was collected in 1937 at Tucumcari, N. Mex. On September 21 succulent plants of hegari, 42 inches high and headed, were selected at 2 to 4 p.m. and divided into leaves plus sheaths, peduncles, internodes, and heads. Short internodes near the base of the stalks were grouped together and composited. Table 3 presents the figures obtained for the HCN yielded by the plant sections.

The leaves again yielded considerably more HCN than the internodes, but the differences were more pronounced than in the former experiment. The ratio of leaf HCN to internode HCN ranged from

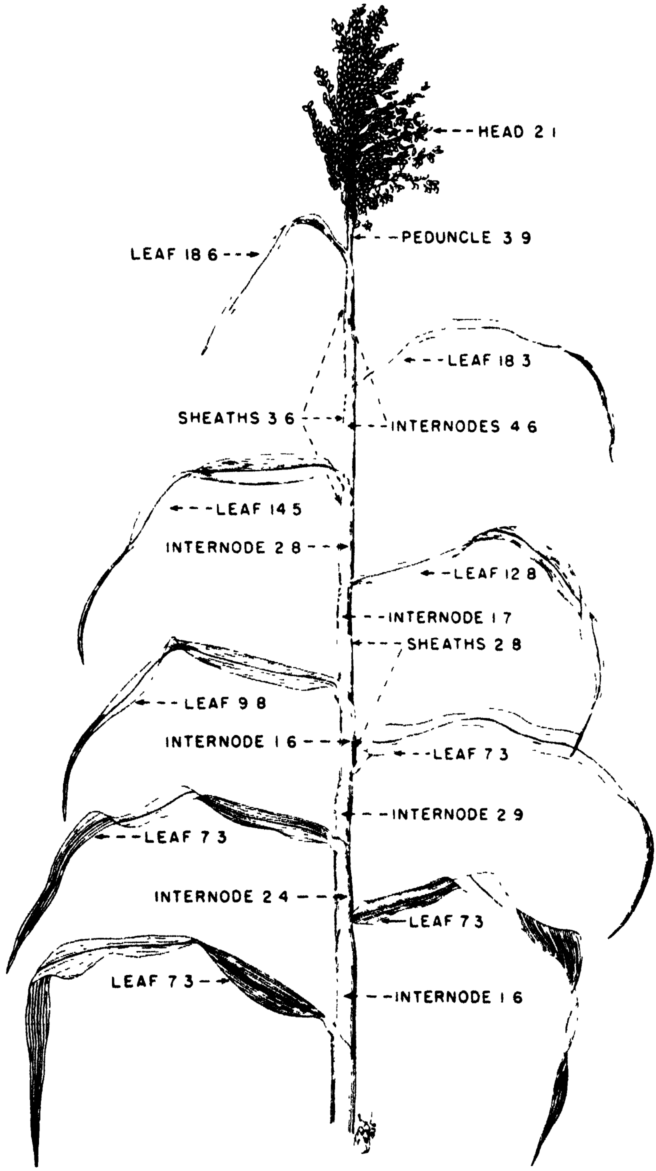

FIG. 1.—Sketch of a sorghum plant showing the HCN content in mg per 100 grams of green tissue of various plant parts. (Data from Table 2.)

10:1 to 25:1 as compared with 3:1 to 5:1 in the earlier experiment. Some of this higher HCN content as compared with the previous experiment may have been due to the improved method of preservation, but much of it is to be attributed to a varietal difference. However, the largest quantity of HCN was not yielded by the topmost

TABLE 3.—*Hydrocyanic acid content in mg per 100 grams of green tissue of different parts of hegari plants at Tucumcari, N. Mex., in 1937, average of two samples.*

Part of plant	Hydrocyanic acid, mg	Part of plant	Hydrocyanic acid, mg
Leaf 1 (top)	39.4	Peduncle	11.0
Leaf 2	47.3	Internode 2	4.6
Leaf 3	52.3	Internode 3	3.5
Leaf 4	56.0	Internode 4	3.0
Leaf 5	50.3	Internode 5	2.6
Leaf 6	46.7	Internode 6	2.1
Leaf 7	51.9	Internode 7	2.3
Leaf 8	51.5	Internodes 8 and 9	2.2
Leaf 9	48.1	Internodes 10 and 11	2.4
Leaf 10	42.9	Bottom internodes	1.5
Leaf 11	33.6	Whole plant	29.1
Leaf 12	27.5	Head	14.1
Leaf 13	19.0		

leaves, the maximum being obtained from the fourth leaf with a progressive increase from the first to the fourth leaf. In the internodes the HCN decreased progressively from the top to the bottom sections.

Samples of certain parts of Early Sumac sorgo plants were taken on two dates at the Akron station in 1937 and preserved in mercuric chloride. They were analyzed 2 and 2½ months after collection. The results are presented in Table 4. The ratio of the HCN content in a leaf to that of the comparable internode is 7:1 for the top and 19:1 for the bottom sections. Comparison of the figures for the whole leaves of the September 8 collection with those for the top and bottom leaves suggests that neither represents the maximum, but that intermediate leaves must have contained considerably more HCN than those analyzed.

TABLE 4.—*Hydrocyanic acid content of different parts of Early Sumac sorgo grown at Akron, Colo., 1937.*

Part of plant	Hydrocyanic acid content in mg per 100 grams of green tissue	
	Sampled Sept. 8	Sampled Sept. 25
Whole plant	—	9.2
Leaves	52.6	67.9
Top leaf	38.7	—
Bottom leaf	32.5	—
Peduncle	5.5	3.8
Top internode	5.5	—
Middle internode	1.7	—
Bottom internode	1.4	1.7
Heads	—	2.3

Further data were obtained from samples collected at Dalhart, Tex., in 1937 and preserved in mercuric chloride. The figures are presented in Table 5.

Hegari samples from plants 36 inches high and from suckers of the same plants 30 inches high gave a ratio of between 7 and 8 to 1 for

TABLE 5.—*Hydrocyanic acid content of different parts of sorghum plants grown at Dalhart, Tex., 1937.*

Date collected	Variety	Part of plant	Height of stalk, in.	Hydrocyanic acid, mg per 100 grams of green tissue
Sept. 2	Hegari	Leaves	36	48.5
2	Hegari	Stems, sheaths, and heads	36	6.5
2	Hegari	Sucker leaf blades	30	48.8
2	Hegari	Sucker stems, sheaths, and heads	30	6.5
Oct. 11	Hegari	Main stalk with head	38	3.8
11	Hegari	Main stalks without head	38	4.5
11	Hegari	Entire sucker	60	13.4
11	Feterita	Side branches, head immature	—	37.3
11	Feterita	Main stalk, head immature	60	5.6

the HCN contents of leaves as compared with mixed stalks, sheaths, and heads. The much higher content of a side branch as compared with the main stalk is indicated by the figures obtained from samples of feterita, collected on October 11. The immature branches yielded over 6 times as much HCN as the mature main stalks. The plants were 60 inches high and the branches 24 to 30 inches long, originating about half way up the stalk.

Experiments conducted with fresh plants collected at Arlington Farm and analyzed immediately showed similar differences between leaves and stalks. An additional experiment was conducted to determine the distribution of the glucoside in the various portions of the leaf itself. The results are presented in Table 6.

TABLE 6.—*Hydrocyanic acid content of parts of sorghum plants grown at Arlington, Va., in 1936.*

Variety	Part of plant	Hydrocyanic acid, mg per 100 grams of green tissue
Spur feterita	Leaves	26.5
Spur feterita	Pith	3.2
Hegari*	Leaves	19.7
Hegari*	Stems	2.2
Hegari†	Whole leaf	12.4
Hegari	Same leaf minus midrib	14.3
Hegari	Midrib	2.4
Hegari	Distal half of leaf	6.7
Hegari	Proximal half of leaf	16.2

*Grown in greenhouse, sampled Nov. 24.
†Field grown, sampled Oct. 1.

These figures show a ratio of 8:1 for Spur feterita and 9:1 for hegari for the relative HCN content of leaves and stems. In the case of the feterita stalks, the cortex which contained the chlorophyll was shaved from the stalk and the pith only was analyzed. The presence of HCN in this non-photosynthesizing tissue suggests either a slight translocation of the glucoside from the leaves or a diffusion of that substance from the green tissues into the interior of the stalk. The

difference in HCN content between the distal and proximal halves of the leaf, being 6.7 mg and 16.2 mg, respectively, in the two portions, indicates a great dissimilarity either in synthetic or in the storing capacity of the tissues. The distal portion is the older tissue. It is of interest that the mean of the figures found, 11.45, is very close to the figure found for the whole leaf, 12.4.

The results obtained in both years indicate that by the time the plants reach the boot stage the leaves contain the greater proportion of nitrile-glucoside and that the upper leaves contain more than those lower and nearer the ground. Data were obtained concerning 15 varieties, all of which showed the same general distribution of the glucoside between leaves and stalks. Four of these varieties were grown at two or more stations and the relationship between leaves and stems in HCN content was maintained.

In outbreaks of sorghum poisoning it often is observed that some of the animals in the herd die while others become sick and recover, and still others are unaffected. These erratic occurrences of poisoning when animals enter a sorghum field may be due in part to the large differences in hydrocyanic acid content between leaves and stalks and between young and older parts of the sorghum plant reported here. Animals that begin eating young leaves or branches might become poisoned within a few minutes, while those eating mostly heads or stalks would ingest only small quantities of HCN and at the same time would have the poisonous effects counteracted to some extent by the glucose and other carbohydrates in these parts.

It is recognized that individual differences in the animals as well as in the plants consumed, and environmental factors, also play a part in the frequency of sorghum poisoning.

SUMMARY

The hydrocyanic acid content of various parts of the sorghum plant was determined in material grown in Texas, New Mexico, Colorado, and Virginia in 1936 and 1937. The HCN content of sorghum leaves was 3 to 25 times that of the corresponding stalks of plants that had reached the boot stage. Heads and leaf sheaths were low in HCN. Upper (younger) leaves contained more HCN than lower (older) leaves. The proximal half of the leaf was higher in HCN than the distal (older) half. The HCN content of leaf blades was six times that of the midribs. The HCN content of stalk internodes decreased progressively downward, the lower (older) internodes containing only small quantities. Axillary (side) branches were much higher in HCN than the older main stalks and in most cases tillers (suckers) were higher in HCN than the older main stalks of the same plants.

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THE EFFECT OF FERTILIZER ON THE LENGTH OF WINTER WHEAT HEADS[1]

R. L. Cook and W. D. Baten[2]

A SURVEY of the results from several experiment stations reveals the fact that wheat is more responsive than most other farm crops to applications of commercial fertilizer. The reasons for this have been set forth by agronomists in various sections of the country. Thatcher (8)[3] found that phosphorus and potassium increased the test weight per bushel and that nitrogen applied in combination with the other elements caused a further increase, but that nitrogen alone or in combination with either phosphorus or potassium caused a decrease in test weight. Bayfield (1) likewise obtained an increase in test weight per bushel as a result of fertilizer application. Millar (4) reported that phosphoric acid fertilizers resulted in plumper kernels of a higher market value.

Winter wheat yields are often depressed by serious winter injury. The fact that fertilizer, properly used, is effective in preventing winter killing of wheat has been observed by Grantham and Millar (3) and by Cook and Millar (2).

Thatcher (8) found that sodium nitrate applied early in the spring increased the number of tillers per plant. Richardson and Fricke (6) found that nitrogen increased the number of head-bearing tillers and also the number of heads per plant at harvest time. On seven experimental fields in central Kansas, Parsons (5) found that nitrogen neither increased the number of heads nor the yields, but that superphosphate fertilizer resulted in greater yields and that the difference in yield was almost all accounted for by the increase in tillering. He reported a slight tendency toward larger heads, especially on one field of inferior soil.

It is commonly believed that increased length of head is a source of greater yields of wheat due to fertilizer application. Grantham and Millar (3) working on sandy soils found the heads of fertilized wheat to be longer than those of unfertilized wheat. Richardson and Gurney (7) showed that ammonium sulfate resulted in vigorous tillering and slightly longer heads.

It is the purpose of this paper to show the effect of fertilizers on the length of wheat heads grown on three silt loam soils during a period of three years and to show how many heads constitute a sample representative of the entire population. A comparison of statistical methods is also included.

SOURCE OF HEADS MEASURED

The heads used in the 1935 measurements were obtained from the Ferden experimental field in Saginaw County. The wheat was grown

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[3]Figures in parenthesis refer to "Literature Cited," p. 742.

in rotation with alfalfa, corn, and oats and the fertilizer treatments were in triplicate. Each bundle or group of heads measured was obtained from 3 rods of row, 1 rod taken at random from each of the three replicates.

The 1936 measurements were taken on heads from the Dilman experimental field in Tuscola County. Each group of heads was obtained from 120 feet of row in each plat.

The 1937 measurements were made on heads from the Drumheller farm in Clinton County. Each group of heads came from 1 rod of row. The field was not an established experimental field, but was simply a farm field where the unfertilized strip was the result of failure of the drill to apply fertilizer.

RESULTS FOR 1935

To facilitate the handling of so many measurements, the data were grouped into 0.3-cm classes. The 1935 frequency distributions for six different fertilizer treatments and an unfertilized control are shown in Table 1. The mean length of head for each treatment, with its standard deviation, is also included. The data show that the unfertilized wheat produced longer heads than did the fertilized wheat.

TABLE 1.—*The effect of fertilizers on the length of winter wheat heads grown on the Ferden farm in 1935.*

Classes, cm	Frequencies with different fertilizers							Complete frequency distribution
	0-0-0 1	0-16-0 2	0-16-8 3	4-12-4 4	4-16-0 5	4-16-4 6	4-16-8 7	
1.35-1.65	0	0	0	0	0	0	2	2
1.65-1.95	0	2	0	0	1	1	4	8
1.95-2.25	3	6	1	2	3	2	3	20
2.25-2.55	5	5	3	5	6	6	8	38
2.55-2.85	4	10	19	12	14	5	9	73
2.85-3.15	11	21	15	19	17	15	24	122
3.15-3.45	12	37	24	29	32	21	21	176
3.45-3.75	26	46	38	51	32	49	33	275
3.75-4.05	39	54	92	82	68	68	87	490
4.05-4.35	51	89	100	97	95	97	86	615
4.35-4.65	69	119	112	127	123	121	143	814
4.65-4.95	65	130	123	112	122	126	174	852
4.95-5.25	100	151	137	145	141	158	154	986
5.25-5.55	118	147	139	171	140	139	143	997
5.55-5.85	79	143	102	121	125	146	119	835
5.85-6.15	76	71	80	93	106	100	82	608
6.15-6.45	50	60	43	42	50	61	41	347
6.45-6.75	41	27	27	28	43	18	21	205
6.75-7.05	19	11	8	13	25	10	6	92
7.05-7.35	18	5	0	4	5	0	3	35
7.35-7.65	3	3	0	1	1	3	0	11
7.65-7.95	1	2	0	1	0	0	1	5
7.95-8.25	2	0	0	0	0	0	0	2
No. stalks	792	1,139	1,063	1,155	1,149	1,146	1,164	7,608
Mean	5.215	4.970	4.901	4.948	5.025	5.000	4.893	4.984
S. D. of mean	.0329	.0275	.084	.073	.0273	.0274	.0272	——

The data presented in Table 1 were analyzed to determine whether the differences between the mean lengths of heads were significant. As shown by the analysis of variance in Table 2, a between treatment means variance of 10.559 compared to a within treatment variance of 0.860 (F equals 12.3) shows that a significant difference exists between at least two of the means.

TABLE 2.—*Analysis of variance for 1935 Ferden wheat head measurements.*

Source of variation	Degrees of freedom	Sum of squares	Variance	Estimate of S. D.
Total	7,607	6601.77	.868	—
Between treatment means	6	63.29	10.559	—
Within treatments	7,601	6538.48	.860	.927

F = 12.3 (significant).

Since the data in Table 1 are grouped data, Shepherd's corrections[4] were made on the "sum of squares" to remove errors due to grouping. The correction is made only for the total "sum of squares". The "sum of squares" for treatments needs no correction unless the means of treatments are grouped into classes. As a rule there are not enough treatment means to group into classes. The analysis of variance after these corrections for grouping were made is shown in Table 3. The F value of 12.4 is practically the same as the F obtained without Shepherd's corrections. Nothing was gained in this case by using the corrections for grouping.

TABLE 3.—*Analysis of variance for 1935 Ferden wheat head measurements after corrections for grouping were made on the sum of squares.*

Source of variation	Degrees of freedom	Sum of squares	Variance	Estimate of S. D.
Total	7,607	6544.713	.8604	—
Between treatment means	6	63.292	10.5487	—
Within treatments	7,601	6481.421	.8527	.923

F = 12.4 (significant).

Using 0.923 as standard deviation with 7,601 degrees of freedom, tests were made for significance between the means shown in Table 1. The difference between the various means, with the standard deviation of the differences and the t values with indications of significance are shown in Table 4. The data show that the mean length of the unfertilized heads was significantly (1% point) greater than the mean length of the heads from any of the fertilized areas.

Certain fertilizers also resulted in longer heads than did other fertilizers. The heads from the areas treated with 4–16–0 were significantly longer than those from areas treated with 4–16–8, 0–16–8, or 4–12–4. Also, 4–16–4 fertilizer produced longer heads than did 4–16–8 or 0–16–8. The heads from plats treated with 0–16–0 were longer than those

[4]Shepherd's correction for the total "sum of squares" is $\left[\Sigma X^2 - \frac{(\Sigma X)^2}{N} - \frac{N}{12}\right] C^2$, where C equals class width and N is the number of measurements.

TABLE 4.—*The differences between the means, with the standard deviation of the differences and t values, of the 1935 Ferden wheat head measurements.*

Description	Differences	S. D. of differences	t
M_1–M_7	.33	.043	7.67**
M_1–M_3	.32	.043	7.44**
M_1–M_4	.27	.043	6.28**
M_1–M_2	.25	.043	5.81**
M_1–M_6	.22	.043	5.12**
M_1–M_5	.19	.043	4.42**
M_5–M_7	.14	.039	3.59**
M_5–M_3	.13	.039	3.33**
M_5–M_4	.08	.039	2.05*
M_6–M_7	.11	.039	2.82**
M_6–M_3	.10	.039	2.56*
M_2–M_7	.08	.039	2.05*

*Significance based on 5% point.
**Significance based on 1% point.

treated with 4–16–8. There seems to be some indication from these results that nitrogen tended to increase the length of head while potash had a tendency to shorten the heads. More measurements would be necessary, however, before these conclusions could be definitely drawn.

It is interesting to note that there were 792 heads in the bundle from the unfertilized plats as compared with 1,063 in the bundle from the plats treated with 0–16–8 and an average of 1,087 heads per bundle for all plats. The percentage $\frac{792}{7,608}$ is significantly smaller than the percentage $\frac{1,087}{7,608}$, hence, the number of heads in the bundle from the control is significantly smaller than the number of heads in the bundles from the treated areas. This increase in number of heads per unit area is due to better germination, the effect of fertilizer in stimulating tillering, or in the prevention of winter killing. All of these factors may have been effective.

RESULTS FOR 1936

The 1936 measurements were confined to heads from one fertilizer treatment and from control areas. As in 1935, the data were grouped into 0.3-cm classes. There were a total of 1,001 heads from 120 feet of row in the unfertilized area and 1,659 heads from an equal area in the fertilized area. Only 998 of the fertilized heads were measured. Since the frequency distributions resemble those obtained in 1935, they are not presented, but the means with their standard deviations are presented in Table 5. The value of t shows that the heads from the plats treated with 4–16–4 were significantly longer than those from the unfertilized area.

These data are in direct conflict with those obtained from the 1935 measurements, but a plausible explanation is available. There were

TABLE 5.—*The effect of fertilizer on the length of winter wheat heads grown on the Dilman farm in 1936.*

Treatment	Means	S. D.
0-16-4	7.40 cm	.03 cm
0-0-0	6.81 cm	.04 cm

$t = \frac{\text{Difference of means}}{\sigma \text{ difference of means}} = 11.4$ (significant).

16.0 heads per foot of row on the unfertilized area in 1935 as compared to 8.3 heads in 1936. The average number of heads per foot of fertilized row in 1935 was 22.9 as compared to 13.8 in 1936. With such a thick stand as was the case in 1935 the effect of fertilizer in increasing the number of heads from 16.0 to 22.9 per foot of row resulted in sufficient crowding actually to shorten the heads. On the other hand, with the relatively thin stand of 1936, an increase in the number of heads from 8.3 to 13.8 per foot did not result in sufficient crowding to decrease the length of head, but rather the fertilizer was effective in producing a longer head.

As already mentioned, Grantham and Millar (3) reported data which showed a larger head as the result of fertilizer application. Their results were obtained on wheat having only 6.6 heads per foot of row on the unfertilized area and 14.2 heads per foot of row on the fertilized area. In other words, where the stand of wheat was relatively thin on the unfertilized land, application of the proper fertilizer resulted in longer heads, but where the stand was thick on the unfertilized land the increase in the number of heads, due to tillering, better germination, or less winter killing, caused sufficient crowding actually to shorten the heads.

RESULTS FOR 1937

The 1937 measurements were made on wheat from a field fertilized with 2-12-6 fertilizer and from an unfertilized strip in the same field. The heads from 1 rod of row were measured in each case. There were 61 heads from the unfertilized row and 202 from the fertilized row. The data presented in Table 6 show the mean lengths of heads and their standard deviations. A t value of 0.2365 shows that there is no significant difference between the two means. It was believed that the lack of significance between the means was due to the small number of measurements. Calculations on the 1935 data relative to the number of measurements necessary for a true sample showed this to be true. A discussion of these calculations follows.

TABLE 6.—*The effect of fertilizer on the length of winter wheat heads grown on the Drumheller farm in 1937.*

Treatment	Means	S. D.
2-12-6	7.17	.09
0-0-0	7.13	.19

$t = \frac{\text{Difference of means}}{\sigma \text{ difference of means}} = 0.24$ (not significant).

NUMBER OF MEASUREMENTS REQUIRED FOR A TRUE SAMPLE

One hundred heads were picked at random from the 1935 bundles. The analysis of variance for the measurements of these heads is given in Table 7. The F value of 2.85, although significant, is much smaller than the F obtained from the entire number of measurements.

TABLE 7.—*Analysis of variance for 1935 Ferden wheat head measurements based upon 100 heads from each treatment.*

Source of variation	Degrees of freedom	Sum of square	Variance	Estimate of S. D.
Total	699	606.32	.867	—
Between treatment means......	6	14.82	2.47	—
Within treatments	693	591.50	.866	.931

F = 2 85 (significant).

The values of t for the 100 heads are given in Table 8. These values for the differences between the fertilized and unfertilized heads are all significant, but one is only to the 5% point and all are smaller than those shown in Table 4 for the same comparisons. Also, the differences between means do not fall in the same order. As a result of the measurement of only 100 heads there were no significant differences between the head lengths of wheat grown with different fertilizers. This shows that significance is not revealed completely from samples of 100 heads.

TABLE 8.—*The differences between means, with the standard deviations of the differences and t values, obtained from 100 head samples of the 1935 Ferden wheat head measurements.*

Description	Differences	S. D. of differences	t
M_1-M_5	.46	.13	3.48**
M_1-M_7	.45	.13	3.46**
M_1-M_3	.39	.13	3.00**
M_1-M_2 & 6	.38	.13	2.92**
M_1-M_4	.33	.13	2.54*

*Significance based on 5% point.
**Significance based on 1% point.

When the entire number of heads were measured the least significant mean difference was approximately 0.1 cm. Since a much larger mean difference was not significant when 100 heads were measured, it was thought desirable to determine theoretically how many heads, drawn at random from each bundle, should be measured to show that a difference of 0.1 cm between two means is significant, and then actually carry out the sampling to check theory. The standard error of each measurement, 0.931, obtained from samples of 100 heads per bundle, was used for determining the theoretical size of the sample necessary to obtain a significant difference of 0.1 cm between two means. The size of the sample, N, was found by the following formula for t:

$$(1)\ t=\frac{\text{Difference of means}}{\text{S. D. of the difference of means}}=\frac{0.10\ \sqrt{N}}{0.931\sqrt{2}}=2.$$

The value of N found from the above formula for t is N> =693 heads.

As a check on these calculations, 700 heads were taken at random from each of the bundles. The analysis of variance for these data is presented in Table 9. The F value of 10.1 approaches that of 12.3 obtained from the entire number of heads, and as shown in Table 10 any difference as great as 0.1 cm is significant. Significance was found in the usual manner from the standard deviation value 0.928, given in Table 9. This verifies the theoretical value for N, the number in the sample.

The data in Table 10 show further that from the 700 head measurements there was not only a significant difference between the length of the unfertilized heads and those fertilized but that some fertilizers produced longer heads than did other fertilizers. The heads from the plats treated with 4–16–0 were significantly longer than those from plats treated with 4–16–8 and 0–16–8. Likewise, heads from the 4–16–4 plats were longer than those from the 4–16–8 plats. These differences are similar to those obtained from the entire number of measurements.

TABLE 9.—*Analysis of variance for 1935 Ferden wheat head measurements based upon 700 heads from each treatment.*

Source of variation	Degrees of freedom	Sum of square	Variance	Estimate of S. D.
Total	4,899	47436.37	——	——
Between treatment means	6	580.03	96.67	——
Within treatments	4,893	46856.34	9.58	.928

F = 10.1 (significant)

TABLE 10.—*The difference between means, with indication of significance, obtained from 700 head samples of the 1935 Ferden wheat head measurements.*

Description	Difference
M_1–M_7	.338**
M_1–M_3	.300**
M_1–M_4	.263**
M_1 M_2	.254**
M_1–M_6	.200**
M_1–M_5	.170**
M_5–M_7	.168**
M_5–M_3	.130**
M_6–M_7	.138**
M_6–M_3	.099*

*Significance based on 5% point.
**Significance based on 1% point.

SUMMARY

The effect of fertilizers on the length of winter wheat heads was determined by measuring large numbers of heads taken from field plats in 1935, 1936, and 1937. The significance of mean differences was shown by analysis of variance. The use of Shepherd's correction for grouped data is illustrated. A statistical study of the number of heads necessary to make a representative sample is included. From

the measurements and calculations, the following conclusions were drawn:

1. The unfertilized wheat produced longer heads in 1935 than did the fertilized wheat. In 1936 the condition was reversed. During both years, fertilizer applications greatly increased the number of heads per foot of row. The number of heads per foot of row on the unfertilized soil was almost twice as great in 1935 as in 1936. Accordingly it is concluded that when crowding is not a factor, fertilizers may be expected to increase the length of heads of winter wheat, but when the stand is so thick that the greater number of heads as a result of the fertilizer causes crowding, the length of the heads may be decreased.

2. Some fertilizers produced longer heads than did other fertilizers.

3. No differences in the results were obtained by using Shepherd's corrections for grouped data.

4. The data obtained from the measurement of 100 heads picked at random from each bundle showed that samples of 100 heads were not truly representative of the entire population.

5. When 700 heads were measured from each bundle, the significant differences were approximately the same as when all the heads were measured. The number "700" was also theoretically checked by calculating "N" from the formula for "t."

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EXTENT OF NATURAL CROSSING IN RICE[1]

H. M. Beachell, C. Roy Adair, N. E. Jodon, L. L. Davis, and Jenkin W. Jones[2]

THE inflorescence of rice is a terminal panicle of perfect flowers. Each floret or spikelet has a branched stigma, six stamens, and two well-developed lodicules. In blooming, the flowers open rapidly and usually the anthers dehisce just before or at the time the flower opens. The flowers may remain open from 1 to 3 hours.

Cultivated rice normally is self-pollinated but some natural crossing occurs. A knowledge of the extent of natural crossing in rice is of importance to the breeder, enabling him to grow material in such a manner as to eliminate crossing as much as possible and also in planning effective roguing. Available evidence indicates that natural crossing has been, and probably still is, an important factor in the origin of rice varieties. This paper presents data on the extent of natural crossing in rice varieties grown under various climatic conditions.

REVIEW OF LITERATURE

In India, Hector (2)[3] estimated 4% of natural crossing in rice in Lower Bengal; McKerral (7) 1.1% in Burma; Roy (12) from 0.1 to 2.9% in cultivated rice and 7.9% in wild rice in the Central Provinces; Parnell, *et al.* (8) from 2 to 4% in Madras. Ramiah (10) stated that, "in hybrid progenies of wild rice, the amount of natural crossing may go up to even 15 to 20% at Coimbatore, Madras"; and Kadam and Patil (5) reported from none to 4.31% with an average of 0.52% crossing in Bombay.

In Japan (Hokkaido), Akemine and Nakamura (1) found an average of 0.9% of natural crossing in 19 varieties grown close together during a 5-year period. The average maximum was 2.32% and the average minimum 0.21%. They also reported that Shimoyama (13) in Japan found 0.084% of natural crossing, and Suzuta and Tomura (14) in Formosa from 0.9 to 1.45%.

Ikeno (4) found no crossing between alternate rows of common and glutinous rice, but he reported that van der Stok in Java found from 1.3 to 4% of natural crossing, and as much as 23% in some cases. Heide (3) in Java placed varieties with respect to pollination in three groups, *viz.*, Open, variable, and closed.

Rodrigo (11) in the Philippine Islands estimated 2.4% of natural crossing in panicles bagged together. In Ceylon, Lord (6) found from 0.34 to 0.67%, and Poggendorff (9) in Australia reported an average of 0.44% of natural crossing.

This brief review indicates that the extent of natural crossing in rice probably depends both on the varieties observed and the climatic conditions under which they were grown.

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[1]Cooperative investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Arkansas, Louisiana, Texas, and California agricultural experiment stations. Received for publication May 17, 1938.

[2]Assistant agronomists and senior agronomist, respectively.

[3]Number in parentheses refers to "Literature Cited," p. 752.

MATERIAL AND METHODS

Rice varieties are classed as common or glutinous on the basis of the nature of the endosperm. Florets of glutinous varieties of rice fertilized by pollen from varieties having common kernels produce common kernels owing to the effect known as xenia. It is possible, therefore, to determine the extent of natural crossing in rice by counting the number of glutinous and common kernels present in glutinous varieties grown adjacent to common varieties. This method, involving an endosperm character, has two distinct advantages over the usual method of detecting natural crosses by means of a dominant character in F_1 plants and then growing F_2 progenies to determine if segregation occurs. First, each seed produced on glutinous plants is classified, hence large numbers are involved. Second, less labor and land are required in growing the material and in making the determinations.

Glutinous and common varieties were grown in alternate rows spaced 1, 2, and 3 feet apart. The paired varieties used began heading at about the same time. The glutinous plants were harvested when mature and the kernels were hulled and classified after they were well dried. The percentage of natural crossing determined in these experiments probably represents the maximum that might occur under the particular conditions with the varieties used because the paired varieties flowered at essentially the same time.

The pairs of varieties used were (a) Asahi Mochi (glutinous) and Colusa (common) early maturing; (b) C. I. No. 5309 (glutinous)[4] and Edith (common), also early maturing varieties but later than Asahi Mochi; (c) C. I. No. 5399 (glutinous) and Blue Rose (common) late maturing; and (d) C. I. No. 3625a (glutinous) and C. I. No. 5205 (common) midseason varieties.

An average of from 30 to 40 glutinous plants per row was grown and examined each year in Texas and Arkansas, and from 15 to 25 or more plants per row in Louisiana and California.

RESULTS OBTAINED

TEXAS

The natural crossing occurring at Texas Agricultural Substation No. 4, Beaumont, is shown in Table 1. The number of glutinous plants examined in the different years that showed crossing ranged from none to 100%. The extent of natural crossing for each pair of varieties at each row spacing varied materially from year to year. In Asahi Mochi, the average amount of natural crossing for the three spacings ranged from 0.04 in 1936 to 1.39% in 1932; in C. I. No. 5309 from 0.03 in 1936 to 0.68% in 1932; in C. I. No. 5399 from 0.25 in 1935 to 0.60% in 1936; and in C. I. No. 3625a from 0.50 in 1933 to 1.63% in 1936.

The glutinous variety C. I. No. 3625a is believed to have originated as a mutation from Shoemed because it is similar to Shoemed in all characters except that the kernels are glutinous.

Panicles of the glutinous varieties were bagged prior to blooming in

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

TABLE 1.—*Natural crossing in rice at Texas Agricultural Substation No 4, Beaumont, Texas.*

Year	Rows 1 foot apart				Rows 2 feet apart				Rows 3 feet apart			
	Plants showing crosses %	Kernels			Plants showing crosses %	Kernels			Plants showing crosses %	Kernels		
		Total No.	Crossed			Total No.	Crossed			Total No.	Crossed	
			No.	%			No.	%			No.	%
Asahi Mochi-Colusa												
1931	94.12	9,779	34	0.35	76.47	8,521	33	0.39	64.29	6,448	15	0.23
1932	100.00	8,220	130	1.58	95.12	13,552	160	1.18	90.91	10,738	163	1.52
1933	53.49	9,597	65	0.68	55.26	12,018	46	0.38	55.26	13,067	54	0.41
1934	71.15	31,991	73	0.23	54.55	20,469	33	0.16	55.00	20,194	45	0.22
1935	60.71	7,676	38	0.50	42.42	7,504	32	0.43	62.86	10,404	33	0.32
1936	4.17	2,144	2	0.09	3.03	3,481	1	0.03	3.03	3,603	1	0.03
C. I. No. 5309-Edith												
1932	66.67	5,119	32	0.63	80.00	6,574	41	0.62	100.00	7,150	56	0.78
1933	48.00	10,798	41	0.38	41.03	13,022	20	0.15	51.16	12,426	30	0.24
1934	23.53	19,918	22	0.11	25.49	18,492	15	0.08	32.61	16,033	17	0.11
1935	31.58	8,357	13	0.16	44.44	7,688	20	0.26	46.34	12,287	24	0.20
1936	4.35	3,162	2	0.06	3.85	2,906	1	0.03	0.00	3,284	0	0.00
C. I. No. 5399-Blue Rose												
1932	67.86	17,409	63	0.36	95.00	24,815	84	0.34	88.00	30,771	88	0.29
1933	82.35	16,762	135	0.81	78.57	29,404	145	0.49	72.22	30,676	107	0.35
1934	87.88	14,648	153	1.04	90.70	35,441	147	0.41	78.57	25,258	133	0.53
1935	68.42	11,143	45	0.40	45.16	13,882	28	0.20	50.00	6,197	6	0.10
1936	59.57	7,867	51	0.65	55.81	9,264	53	0.57	75.51	12,344	73	0.59
C. I. No. 3625a-C. I. No. 5205												
1932	88.89	11,386	90	0.79	92.00	17,166	142	0.83	82.14	20,873	189	0.91
1933	66.67	14,723	81	0.55	83.78	26,877	124	0.46	73.08	27,879	141	0.51
1934	100.00	36,525	594	1.63	93.02	39,672	152	0.38	85.71	25,501	146	0.57
1935	91.18	12,043	189	1.57	90.91	14,355	144	1.00	81.58	15,676	127	0.81
1936	90.91	5,988	113	1.89	89.74	9,256	144	1.56	88.37	9,245	141	1.52

1935, 1936, and 1937 to determine whether kernels of the common type might arise by mutation in glutinous varieties. In 1935 one common kernel was found on Asahi Mochi but none in the other varieties. This kernel could have resulted from a natural cross prior to bagging. In 1936, 6 common kernels, or 0.028%, were found in a total of 2,110 classified from C. I. No. 3625a. In 1937, only 1 common kernel was found in a total of 18,289 classified from bagged panicles of C. I. No. 3625a. This indicates that in C. I. No. 3625a mutation from glutinous to common kernels may occur, but if it does, the small numbers involved would not materially affect determinations of natural crossing.

ARKANSAS

The extent of natural crossing at the Rice Branch Experiment Station, Stuttgart, Ark., is given in Table 2. The number of glutinous plants examined from year to year that showed crosses varied from 10 to 100%. There was a marked variation from year to year in the extent of natural crossing for each pair of varieties in all row spacings. The average percentage of natural crossing in Asahi Mochi for all three spacings varied from 0.26 in 1931 to 1.94% in 1934; in C. I. No. 5309 from 0.25 in 1935 to 0.34% in 1936; in C. I. No. 5399 from 0.05 in 1935 to 0.25% in 1934; and in C. I. No. 3625a from 0.35 in 1936 to 0.75% in 1935.

LOUISIANA

Paired varieties were grown at the Rice Experiment Station, Crowley, La., as in the other tests, except in 1935. In that year the border rows consisted of a mixture of three or four common varieties, rather than a single variety. This change may have increased the extent of natural crossing in C. I. No. 5399 but for the other glutinous varieties the percentage was lower than in previous years. The results are shown in Table 3.

The average percentage of natural crossing in Asahi Mochi for the three spacings varied from 0.32 in 1934 to 1.07% in 1933; in C. I. No. 5309 from 0.31 in 1935 to 0.72% in 1934; in C. I. No. 5399 from 0.03 in 1934 to 0.18% in 1935; and in C. I. No. 3625a from 0.25 in 1935 to 1.59% in 1934.

CALIFORNIA

The results at the Biggs Rice Field Station, Biggs, Calif., are given in Table 4. The number of glutinous plants examined from year to year showing crosses ranged from 6.67 to 96%. The extent of natural crossing in California was much less than that recorded at the other stations. The average percentage of natural crossing in Asahi Mochi for the three spacings ranged from 0.04 in 1933 to 0.49% in 1937; and in Selection No. 299, which is similar to C. I. No. 5309, from 0.06 in 1935 to 0.34% in 1937.

EFFECT OF ROW SPACING

The natural crossing occurring in the experiments at all four stations is summarized in Table 5.

TABLE 2.—*Natural crossing in rice at the Rice Branch Experiment Station, Stuttgart, Ark.*

Year	Rows 1 foot apart				Rows 2 feet apart				Rows 3 feet apart			
	Plants showing crosses %	Kernels			Plants showing crosses %	Kernels			Plants showing crosses %	Kernels		
		Total No.	Crossed			Total No.	Crossed			Total No.	Crossed	
			No.	%			No.	%			No.	%
Asahi Mochi-Colusa												
1931	63.04	23,582	84	0.36	58.33	20,632	48	0.23	46.51	23,389	44	0.19
1932	38.46	6,624	17	0.26	33.33	5,499	19	0.35	57.89	5,432	18	0.33
1933	57.50	11,556	41	0.34	61.11	8,874	44	0.50	54.29	6,880	36	0.52
1934	100.00	19,083	513	2.69	100.00	21,908	409	1.87	100.00	18,526	235	1.27
1935	63.64	2,156	9	0.42	36.00	4,384	9	0.21	42.86	4,796	18	0.38
C. I. No. 5309-Edith												
1934	20.83	6,732	19	0.28	37.25	10,628	20	0.19	44.68	12,085	41	0.34
1935	27.03	5,223	14	0.27	41.94	4,928	14	0.28	39.53	9,260	20	0.22
1936	36.73	10,738	27	0.25	55.77	19,535	51	0.26	75.00	21,189	97	0.46
C. I. No. 5399-Blue Rose												
1934	50.00	12,138	52	0.43	55.10	16,972	48	0.28	39.58	20,145	24	0.12
1935	10.81	9,167	4	0.04	10.00	9,185	3	0.03	18.75	12,170	7	0.06
1936	36.54	16,271	25	0.15	44.23	29,595	47	0.16	35.09	39,978	33	0.08
C. I. No. 3625a-C. I. No. 5205												
1933	40.00	9,050	125	1.38	39.47	12,046	54	0.45	27.50	12,810	40	0.31
1935	52.08	11,602	84	0.72	58.00	15,478	130	0.84	59.52	12,898	86	0.67
1936	30.00	11,792	34	0.29	67.57	22,173	65	0.29	60.00	27,968	118	0.42

TABLE 3.—*Natural crossing in rice at the Rice Experiment Station, Crowley, La.*

Year	Rows 1 foot apart: Kernels Total No.	Rows 1 foot apart: Crossed No.	Rows 1 foot apart: Crossed %	Rows 2 feet apart: Kernels Total No.	Rows 2 feet apart: Crossed No.	Rows 2 feet apart: Crossed %	Rows 3 feet apart: Kernels Total No.	Rows 3 feet apart: Crossed No.	Rows 3 feet apart: Crossed %
				Asahi Mochi-Colusa					
1931	4,411	20	0.45	5,138	21	0.41	5,732	9	0.16
1933	2,335	21	0.90	—	—	—	1,512	20	1.32
1934	2,716	15	0.55	2,122	5	0.24	3,068	5	0.16
1935	3,566	12	0.34	2,462	7	0.28	2,599	9	0.35
				C. I. No. 5309-Edith					
1933	913	2	0.22	822	6	0.73	2,140	9	0.42
1934	3,258	19	0.58	3,677	30	0.82	4,521	33	0.73
1935	1,943	6	0.31	3,425	8	0.23	2,783	11	0.40
				C. I. No. 5399-Blue Rose					
1933	3,046	1	0.03	9,701	5	0.05	2,174	5	0.23
1934	4,353	0	0.00	8,420	2	0.02	6,321	4	0.06
1935	4,642	10	0.22	7,842	15	0.19	12,455	19	0.15
				C. I. No. 3625a-C. I. No. 5205					
1932	4,163	52	1.25	7,031	61	0.87	7,510	85	1.13
1933	526	15	2.85	1,512	0	0.00	633	0	0.00
1934	6,164	209	3.39	8,473	71	0.84	7,117	65	0.91
1935	6,840	13	0.19	8,310	17	0.20	7,913	28	0.35

In Arkansas the average percentage of natural crossing in Asahi Mochi was considerably higher in rows spaced 1 foot apart than in rows spaced 2 or 3 feet apart, but in the other states the differences for the three spacings were not large. In C. I. No. 5309 the space between the rows did not materially affect the extent of natural crossing at any station. This was also true for C. I. No. 5399. The average percentage of natural crossing in C. I. No. 3625a in Arkansas, Louisiana, and Texas, however, was considerably higher in rows spaced 1 foot apart than in rows spaced 2 or 3 feet apart.

The results indicate that a space of 3 feet between varieties of similar maturity is not sufficient to eliminate natural crossing, but it may reduce it in some cases, though hardly enough to be of practical importance.

The average percentage of natural crossing for the three spacings for Asahi Mochi was 0.84 in Arkansas, 0.48 in Texas, 0.40 in Louisiana, and 0.16 in California; for C. I. No. 5309 (selection No. 299 in California) 0.53 in Louisiana, 0.30 in Arkansas, 0.23 in Texas, and 0.16 in California; for C. I. No. 5399, 0.46 in Texas, 0.15 in Arkansas, and 0.10 in Louisiana; for C. I. No. 3625a, 0.93 in Louisiana, 0.88 in Texas, and 0.54 in Arkansas.

The average percentage of natural crossing in the four varieties at the three spacings was 0.56 in Texas, 0.51 in Louisiana, 0.48 in Ar-

TABLE 4.—*Natural crossing in rice at the Biggs Rice Field Station, Biggs, Calif.*

Year	Plants showing crosses %	Rows 1 foot apart			Plants showing crosses %	Rows 2 feet apart			Plants showing crosses %	Rows 3 feet apart		
		Kernels				Kernels				Kernels		
		Total No.	Crossed			Total No.	Crossed			Total No.	Crossed	
			No.	%			No.	%			No.	%
						Asahi Mochi-Colusa						
1933	18.00	18,503	16	0.09	20.00	35,632	9	0.03	40.00	39,291	14	0.04
1934	62.50	20,437	30	0.15	60.00	30,952	25	0.08	60.00	31,822	27	0.08
1935	26.67	5,438	5	0.09	20.00	4,723	3	0.06	6.67	4,228	1	0.02
1936	52.00	14,864	23	0.15	83.33	23,979	63	0.26	72.00	23,618	30	0.13
1937	88.00	17,470	63	0.36	84.00	16,065	81	0.50	96.00	13,187	85	0.64
						Selection No. 299-Edith						
1934	58.33	11,461	19	0.17	62.50	19,418	23	0.12	62.50	23,320	15	0.06
1935	33.33	5,264	5	0.09	13.33	5,999	2	0.03	20.00	5,392	3	0.06
1936	72.00	13,966	31	0.22	68.00	19,994	43	0.22	60.00	20,094	23	0.11
1937	60.00	6,649	30	0.45	52.00	7,434	24	0.32	44.00	7,566	20	0.26

TABLE 5.—*Summary of the natural crossing studies in rice for the years grown at the Texas, Arkansas, Louisiana, and California stations.*

Distance from common variety	Texas			Arkansas			Louisiana			California		
	Kernels			Kernels			Kernels			Kernels		
	Total No.	Crossed		Total No.	Crossed		Total No.	Crossed		Total No.	Crossed	
ft.		No.	%		No	%		No.	%		No.	%
	Asahi Mochi-Colusa											
1	69,407	342	0.49	63,001	664	1.05	13,028	68	0.52	76,712	137	0.18
2	65,545	305	0.47	61,297	529	0.86	9,722	33	0.33	111,351	181	0.16
3	64,454	311	0.48	59,023	351	0.59	12,871	43	0.33	112,146	157	0.14
Total	199,406	958	0.48	183,321	1,544	0.84	35,621	144	0.40	300,209	475	0.16
	C. I. No. 5309*-Edith											
1	47,354	110	0.23	22,693	60	0.26	6,114	27	0.44	37,340	85	0.23
2	48,682	97	0.20	35,091	85	0.24	7,924	44	0.56	52,845	92	0.17
3	51,180	127	0.25	42,534	158	0.37	9,444	53	0.56	56,372	61	0.11
Total	147,216	334	0.23	100,318	303	0.30	23,482	124	0.53	146,557	238	0.16

	C. I. No. 5399-Blue Rose											
1	67,829	447	0.66	37,576	81	0.22	12,041	11	0.09	—	—	—
2	112,806	457	0.41	55,752	98	0.18	25,963	22	0.08	—	—	—
3	105,246	407	0.39	72,293	64	0.09	20,950	28	0.13	—	—	—
Total	285,881	1,311	0.46	165,621	243	0.15	58,594	61	0.10	—	—	—
	C. I. No. 3625a-C. I. No. 5205											
1	80,665	1,067	1.32	32,444	243	0.75	17,693	289	1.63	—	—	—
2	107,326	706	0.66	49,697	249	0.50	25,326	149	0.59	—	—	—
3	99,174	744	0.75	53,676	244	0.45	23,173	178	0.77	—	—	—
Total	287,165	2,517	0.88	135,817	736	0.54	66,192	616	0.93	—	—	—
	Total All Varieties											
1	265,255	1,966	0.74	155,714	1,048	0.67	48,876	395	0.81	114,052	222	0.19
2	334,359	1,565	0.47	201,837	961	0.48	68,935	248	0.36	164,196	273	0.17
3	320,054	1,589	0.50	227,526	817	0.36	66,438	302	0.45	168,518	218	0.13
Grand total	919,668	5,120	0.56	585,077	2,826	0.48	184,249	945	0.51	446,766	713	0.16
Grand total all stations....	...	...	...	...	...	...	...	...	...	2,135,760	9,604	0.45

*Selection No. 299 used in California.

kansas, and for two varieties 0.16 in California. At all stations a total of 2,135,760 kernels was classified and of this number 9,604, or 0.45%, were common (crossed).

In 1933 and 1934 the glutinous varieties were grown at Beaumont, Texas, in three-row plats separated by at least 30 feet from any common early-maturing variety. Plants from the center rows of each plat were examined for natural crossing. In the early-maturing varieties, Asahi Mochi and C. I. 5309, the percentage of natural crossing was 0.03 and 0.05, respectively, in 1933 and 0.02 and 0.10 in 1934. In the two later-maturing varieties, the percentage of natural crossing was 0.27 and 0.30, respectively, in 1933 and 0.05 and 0.21 in 1934.

The later-maturing varieties were more exposed to foreign pollen than the early varieties, because, as the season advanced, common varieties nearer the plats began to head. The results for the early varieties indicate that natural crossing may occur at a distance of 30 feet or more.

The percentage of natural crossing within a variety probably is similar to that occurring between adjacent varieties. If this is the case, the percentages given in the preceding tables represent not more than half the natural crossing that actually occurred. Crossing within a variety, however, is of little importance for the breeder is concerned mainly with that which occurs between pure-breeding varieties and selections.

Opportunity for natural crossing occurs when flowers open before the anthers are fully developed and when the anthers fail to dehisce promptly at blooming time. Insects that feed on rice pollen may also cause natural crossing.

SUMMARY

The results presented indicate that (a) the extent of natural crossing in a given variety in the same locality varied considerably from year to year; (b) varieties differed materially in extent of natural crossing; (c) in some varieties more natural crossing occurred in rows spaced 1 foot apart than in rows spaced 2 or 3 feet apart, while in others this was not the case; (d) seasonal and environmental conditions had a marked influence on the extent of natural crossing in all varieties; and (e) much more natural crossing occurred in the Southern States than under the higher temperature and lower humidity conditions prevailing in California. The extent of natural crossing ranged from none to 3.39%, and the average for all stations was 0.45%.

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THE CORRELATION AMONG VARIOUS CONSTITUENTS OF FORAGE PLANTS[1]

J. E. GREAVES[2]

DURING the fall and winter of 1931, 72 samples of forage plants were collected on the Trout Creek winter range in Juab County, Utah (2)[3]. They represented the following 16 species which composed the bulk of the forage plants in this district:

Artemisia tridentata	*Atriplex confertifolia*
Artemisia nova	*Gutierrezia sarothrae*
Artemisia spinescens	*Chrysothamnus nauseosus*
Ephedra nevadensis	*Chrysothamnus viscidiflorus*
Kochia vestita	*Oryzopsis hymenoides*
Hilaria jamesii	*Salsola pestifer*
Atriplex canescens	*Juniperus utahensis*
Atriplex nuttallii	*Eurotia lanata*

Great care was used in their collection. From 6 to 8 pounds of leaves and stems, the portions ordinarily browsed by sheep, were hand picked from representative plants. The whole sample was dried, ground, and then sampled for analyses. From three to six samples of each plant species were collected in this manner from different localities and these were analyzed separately for crude fibre, crude fat, crude protein, ash, calcium, magnesium, phosphorus, and sulfur according to the methods of the Association of Official Agricultural Chemists (1) The nitrogen-free extract was calculated by subtracting the crude fibre, crude fat, crude protein, and ash from the total dry weight.

The correlation among the various constituents was then calculated according to the following formula given by Wallace and Snedecor (3):

$r = \frac{\Sigma AX - (\Sigma A)\ Mx}{\sqrt{\Sigma A^2 - (\Sigma A)\ Ma}\ \sqrt{\Sigma X^2 - (\Sigma X)\ Mx}}$, where A and X equal the two variables and $Mx = \frac{\Sigma X}{N}$ and $Mz = \frac{\Sigma A}{N}$.

The mean ash content of the 16 plants varied from 4.45% in the case of *Juniperus utahensis* to 21.55% in the case of *Artemisia spinescens*. There was also a great variation in the ash of the same species probably due to age, soil, and amount of water received during the growing period. Seven of the plants carried over 10% ash, three having 20%. About half of the plants analyzed carried more ash than alfalfa hay. In Table 1 is given the correlation found to exist between ash and the other constituents determined.

[1]Contribution from the Department of Chemistry and Bacteriology, Utah Agricultural Experiment Station, Logan, Utah. Received for publication May 19, 1938.

[2]Bacteriologist. Grateful acknowledgment is expressed to A. C. Esplin and L. A. Stoddart for permission to use these results in this paper; also to Professor Aaron F. Bracken for many helpful suggestions.

[3]Figures in parenthesis refer to "Literature Cited," p. 759.

TABLE 1.—*Correlation between ash of 16 forage plants and other constituents.*

Constituent	r	Constituent	r
Calcium	0.316	Crude protein	−0.056
Magnesium	0.784	Crude fat	−0.819
Phosphorus	−0.350	Crude fiber	0.083
Sulfur	0.542	Nitrogen-free extract	0.157

A highly significant relationship between the ash of these forage plants and the quantity of magnesium, sulfur, and calcium which they carry is shown by the respective correlations. However, a high ash content is associated with a low crude fat content, and likewise the phosphorus content is negatively correlated with the ash content. There is probably little or no relationship between the ash content of these plants and their crude protein or nitrogen-free extract content.

The calcium content of these plants varied from 0.40% in the *Hilaria jamesii* to 2.10% in the *Salsola pestifer*. They were grown in calcareous soil and would all be classed as high in calcium, yet a wide variation existed in the same species.

From Table 2 a significant correlation is shown to exist between the calcium content of these plants and the ash, calcium and sulfur, and calcium and magnesium content. The soils from which these plants were collected contained large quantities of calcium, magnesium, and sulfur; hence, the close relationship between available nutrients in the soils and the concentrates in the plants. The quantity of phosphorus in the soil is high, yet that available to the growing plant decreases with the soil concentration of calcium; thus the reason for the negative correlation between calcium and phosphorus. From the viewpoint of animal nutrition this is very significant and points to the conclusion that many of these plants when fed to animals should be supplemented with a sodium or potassium salt of phosphorus. The fat and carbohydrate contents of these plants decrease as the calcium increases, as indicated by the correlations, showing that the nutritive values of these high-calcium forage plants are as a rule less than the low-calcium forage plants.

TABLE 2.—*Correlation existing between calcium and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	0.361	Crude protein	0.219
Magnesium	0.304	Crude fat	−0.284
Phosphorus	−0.532	Crude fibre	0.054
Sulfur	0.396	Nitrogen-free extract	−0.503

The mean magnesium content of these plants varies from 0.15% in the cases of *Hilaria jamesii* and *Oryzopsis hymenoides* to 0.91% in the case of *Kochia vestita*. The average for all was 0.41%. The variation between samples is also wide, for example, one sample of *Salsola pestifer* carried only 0.04% magnesium, whereas a different sample grown in a different locality carried 0.21%.

As shown by the correlation coefficients (Table 3), there is a direct relationship between the magnesium, ash, and calcium content of these forage plants and a negative correlation between the magnesium and crude fat. Apparently no relationship was found to exist between the magnesium and the other determined constituents.

TABLE 3.—*Correlation existing between magnesium and other constituents of forage plants*

Constituent	r	Constituent	r
Ash	0.784	Crude protein	0.096
Calcium	0.304	Crude fat	−0.264
Phosphorus	0.208	Crude fibre	−0.109
Sulfur	0.173	Nitrogen-free extract	−0.067

The mean phosphorus content of the 16 species of plants was 0.18% with a wide variation within a species and between different species. Nearly all of these 16 dominant forage plants would meet an animal's phosphorus needs, but nearly all were carrying excessive quantities of calcium, hence the phosphorus-calcium ratio is out of balance. There is a highly significant correlation (Table 4) between phosphorus and crude protein and phosphorus and crude fat with an inverse relationship between the phosphorus and ash and phosphorus and crude fibre. Hence, insofar as these plants are concerned, the phosphorus content is a good measure of the nutritive value of the plant. However, in order to get the best results from feeding these plants, a phosphorus supplement should be available.

TABLE 4.—*Correlation found between phosphorus and other constituents of forage plants.*

Constituents	r	Constituents	r
Ash	−0.350	Crude protein	0.444
Calcium	−0.532	Crude fat	0.677
Magnesium	0.208	Crude fibre	−0.530
Sulfur	0.176	Nitrogen-free extract	−0.151

The mean sulfur content of the 16 plants varied from 0.14% in the case of *Hilaria jamesii* to 0.59% in *Atriplex nuttallii*. Many of the plants are richer in sulfur than alfalfa; however, before they could be compared from a nutritive standpoint one must know the percentages of the sulfur which is organic. The fact that "r" is a significant value in the cases of calcium and magnesium (Table 5) indicates that the plants carry inorganic sulfur. The organic sulfur would likely all be contained in the crude protein where a correlation of 0.491 is shown.

TABLE 5.—*Correlation between sulfur and other constituents of forage plants.*

Constituents	r	Constituents	r
Ash	0.542	Protein	0.491
Calcium	0.396	Fat	−0.238
Magnesium	0.173	Crude fibre	−0.348
Phosphorus	0.176	Nitrogen-free extract	−0.227

All of the plants were rather poor in crude protein. Only one, *Artemisia spinescens*, is as rich in crude protein as alfalfa. *Juniperus utahensis*, *Gutierrezia sarothrae*, *Chrysothamnus nauseosus*, and *Chrysothamnus viscidiflorus* have a mean crude protein percentage equal to that of timothy hay; whereas, *Oryzopsis hymenoides* and *Hilaria jamesii* carry no more crude protein than oat and barley straw.

The correlation (Table 6) is high between the crude protein and phosphorus and crude protein and sulfur which may indicate that considerable of the sulfur and phosphorus are in the organic form.

TABLE 6.—*Correlation between crude protein and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	−0.056	Sulfur	0.491
Calcium	0.219	Crude fat	0.177
Magnesium	0.096	Crude fibre	−0.342
Phosphorus	0.444	Nitrogen-free extract	−0.165

A wide variation existed in the crude fat between different families of these plants and likewise between samples collected from the same species. For example, some samples of *Chrysothamnus viscidflorus* contained five times as much crude fat as did others. The crude fat content of *Juniperus utahensis* was 30 times that of *Hilaria jamesii*. All of the plants analyzed, except *Artemisia spinescens*, *Salsola pestifer*, *Oryzopsis hymenoides*, *Atriplex confertifolia*, and *Hilaria jamesii*, contained more crude fat than dry alfalfa hay. As shown by the data in Table 7, the crude fat and phosphorus were positively correlated with a negative correlation between crude fat and ash, crude fat and calcium, crude fat and magnesium, crude fat and sulfur, and crude fat and crude fibre.

TABLE 7.—*Correlation between crude fat and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	−0.819	Sulfur	−0.238
Calcium	−0.284	Crude protein	0.177
Magnesium	−0.264	Crude fibre	−0.342
Phosphorus	0.677	Nitrogen-free extract	−0.165

Of the 16 forage plants analyzed, all except 6 have a mean fibre content of over 20%. *Ephedra nevadensis* carried 40% crude fibre; however, the percentage of crude fibre varied in the same species, old plants carrying much more than young plants. Leaves, stems, and stocks of some plants are tender, whereas in other plants they are woody. *Ephedra nevadensis* with its 40% of crude fibre carried 2.5 times as much as did either *Kochia vestita* or *Atriplex canescens*.

As the crude fibre increased, the phosphorus, crude protein, crude fat, and nitrogen-free extract all decreased, thus indicating that a plant having a high crude fibre content is exceptionally low in nutritive value. The correlations are shown in Table 8.

TABLE 8.—*Correlation between crude fibre and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	0.083	Sulfur	0.348
Calcium	0.054	Crude protein	−0.342
Magnesium	−0.109	Crude fat	−0.513
Phosphorus	−0.530	Nitrogen-free extract	−0.535

The mean nitrogen-free extract of the 16 species of forage plants varied from 35.5% to 50 1%. There was a variation of nitrogen-free extract in the same species of from 5 to 25% between the minimum and the maximum.

As shown by the correlation coefficient (Table 9), with the single exception of fat, all other constituents determined decreased as the nitrogen-free extract increased, the value of "r" being in the cases of calcium, crude fat, and crude fibre highly significant.

TABLE 9.—*Correlation between nitrogen-free extract and other constituents of forage plants.*

Constituents	r	Constituents	r
Ash	0.157	Sulfur	−0.227
Calcium	−0.502	Crude protein	−0 165
Magnesium	−0.067	Crude fat	0.325
Phosphorus	−0.151	Crude fibre	−0.535

SUMMARY

Seventy-two samples, representing 16 species of forage plants growing on the Trout Creek winter range in Juab County, Utah, were analyzed for calcium, magnesium, phosphorus, sulfur, crude fat, crude protein, and nitrogen-free extract. The correlation existing between pairs of these constituents has been calculated with the following results:

A highly significant correlation was found to exist between ash and calcium, ash and magnesium, ash and sulfur, calcium and magnesium, calcium and sulfur, phosphorus and crude protein, phosphorus and crude fat, and sulfur and crude protein.

A highly significant negative correlation was found to exist between ash and phosphorus, ash and crude fat, calcium and phosphorus, calcium and nitrogen-free extract, phosphorus and crude fibre, sulfur and crude fibre, crude fibre and crude protein.

These results indicate that the organic sulfur varies, and it is necessary to determine the quantity which is inorganic before one can state its nutritive value. Insofar as these plants are concerned, a total phosphorus determination is a good indication of the nutritive value of the plant because phosphorus and sulfur, phosphorus and protein, and phosphorus and crude fat vary directly, whereas the phosphorus and crude fibre and phosphorus and total ash vary inversely. The fact that the phosphorus and calcium vary inversely indicates that from the nutritional standpoint one must balance the calcium in relation

to the phosphorus. This unbalanced relationship may be the reason why supplements used in connection with these forage plants give such poor results.

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SELF-POLLINATION IN RAPE[1]

VON G. SUN[2]

IT is recognized that in breeding groups of plants which are frequently or naturally cross-pollinated, some method of controlling pollination must be developed in order to obtain selfed seed and isolate inbred lines. Considerable attention has been focused on methods of selfing rape since the writer began his rape breeding experiments in 1933.

From a practical standpoint any satisfactory method of self-pollination must be (a) simple in operation, (b) inexpensive, and (c) must ensure an adequate amount of selfed seed. This study is a report of different methods of selfing rape in order to meet the above requirements.

LITERATURE REVIEW

Pearson (3)[3], in studies of breeding methods with cabbage, found that the application of pollen from the same plant was as effective as foreign pollen if applied at the proper time. He used a method of pollinating in the bud stage as a means of obtaining selfed seed. The inflorescences were enclosed in paper bags to prevent crossing by insects.

Kakizaki and Kasai (2) found that bud pollination in *Brassica pekinensis* and *Raphanus sativus* materially increased the amount of selfed seed obtained. This was true particularly in highly self-incompatible plants.

Stout (4) found that selecting during generations of selfing in *Brassica pekinensis* produced no completely self-fertile lines. He found that the greatest amount of selfed seed was obtained in the middle of the flowering period.

In 1934, Sun (5) obtained an average of 63% seed setting in open-pollinated inflorescences of rape as compared with only 21% in inflorescences enclosed in glassine bags to prevent crossing. In 1935 the percentages of seed set were 72 and 23, respectively. While the amount of seed set when selfing was markedly lower than in open-pollinated inflorescences, it would be sufficient for continued inbreeding.

MATERIAL AND METHODS

Three different methods of obtaining selfed seed in inbred lines of rape were studied, *viz.*, (a) without removal of the terminal buds, (b) with removal of the terminal buds, and (c) bud pollination with terminal buds removed. Paper bags were used to enclose the inflorescences to prevent crossing.

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[2]Associate Professor. The writer wishes to express his thanks to Messrs. S. J. Young and P. Kong, senior students in the College of Agriculture of the National University of Chekiang, for data made available in the course of the experiment.

[3]Figures in parenthesis refer to "Literature Cited," p. 762.

It had been observed in previous studies that the indeterminate habit of growth of the inflorescence led to poor development of the silliqua due to elongation of the branches. By removing the terminal buds such elongation could be stopped.

At the time of early blooming, about March 13 to 20, 1937, four plants of each inbred line of rape in the nursery were selected at random and each plant treated in each of the three ways given above. Under method A, a single inflorescence on each plant was enclosed in a paper bag; for method B 10 buds were left on each inflorescence and the flowers allowed to self; while for method C 10 buds in each inflorescence were pollinated by hand, using pollen from the same plant. Paper bags 4 x 14 inches in size were used to enclose the inflorescences under all three methods. Any flowers which appeared to be open were removed before bagging. The number of seeds obtained from each inflorescence was determined after harvest and the data analyzed by the analysis of variance.

EXPERIMENTAL RESULTS

The number of seeds set on the inflorescences of four plants per inbred line by each of the three methods of selfing is given in Table 1.

TABLE 1.—*Number of seeds set in four inflorescences by three methods of selfing in each of 10 inbred lines of rape grown in 1937.*

Strain No.	Methods of selfing*			Average
	A	B	C	
95-1-9	27	10	117	51
92-2-1	64	36	291	130
35-1-17	218	48	284	183
14-2-1	270	43	452	255
Number lost	29	4	493	175
72-2-1	359	108	395	287
Number lost	26	27	273	109
97-3-8	98	33	74	68
91-5-2	23	1	185	70
91-5-2	172	0	256	143
Average	129	31	282	

*A = without removal of terminal buds
B = with removal of terminal buds.
C = bud pollination of 10 buds per inflorescence, terminal buds removed.

In the above table it is seen readily that the greatest amount of seed was obtained by method C i.e., by bud pollination. The results by methods B and C are directly comparable, since 10 buds were left on each inflorescence. By method A the terminal buds were not removed, allowing a greater possible number of flowers to develop and set seed. In spite of the greater number of flowers under method A, less than half as much seed was obtained on the average as with method C. The different strains varied considerably in fertility.

A test was set up also to determine whether there was a difference in amount of selfed seed obtained on the same inflorescence in differ-

ent parts of the flowering period. Twenty plants in each of two inbred lines were selected and three comparable branches on each plant bagged on the same day. Only 10 of the largest, unopened buds were left on each branch. These were selfed artificially, one plant per line being selfed on each of the following days: March 16, 22, and 28. The total number of silliqua and number of seeds obtained from each of the three treatment periods are given in Table 2.

TABLE 2.—*Number of silliqua and number of seeds obtained from three treatment periods of 20 plants selected from each of two inbred lines.*

Color of seed of inbred line	No. of silliqua for selfing period			No. of seeds for selfing period		
	Mar. 16	Mar. 22	Mar. 28	Mar. 16	Mar. 22	Mar. 28
Red	10	37	39	60	178	83
Yellow	22	26	31	61	67	77

It is apparent that the number of seeds obtained was greatest in the middle of the flowering period in the case of the red-seeded lines. There seems to have been essentially no difference in different periods of selfing in the yellow-seeded line.

SUMMARY

1. Bud pollination proved to be the most effective method for obtaining selfed seed in rape.

2. Some evidence was found that the middle of the flowering period may be the most efficient stage for artificially selfing rape.

3. Covering the inflorescence with a paper bag gave sufficient seed so that this method appears feasible as a practical method of selection in self-pollinated lines.

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INDUCING GERMINATION IN *ORYZOPSIS HYMENOIDES* FOR RANGE RESEEDING[1]

L. A. STODDART AND K. J. WILKINSON[2]

VAST areas of range land in the western United States are now or were formerly dominated by the perennial bunch-grass *Oryzopsis hymenoides* (Roem. and Shult.) Ricker, known commonly as Indian ricegrass. Since this grass is a climax species and as such has demonstrated its ability to thrive under climatic conditions existant throughout most of the dry lands west of the Great Plains, it is ecologically sound that it be given consideration in many revegetation programs in the West.

Indian ricegrass grows from Canada to New Mexico and in all states west of Montana, Nebraska, and Texas. It thrives best on foothills and plains, especially where the soil is well aerated as in rocky or sandy areas. Even rather rapidly shifting sands hold no peril for this grass, as it can elongate its basal internodes, produce adventitious roots at the nodes, and thus re-establish itself at a higher level. *Oryzopsis hymenoides* is typically without rhizomes and forms an open and widely spaced bunch cover. It is highly valued as a forage species, and it is remarkably resistant to heavy grazing.

Because of the apparent adaptability of Indian ricegrass to western ranges many trial seedings have been made by various agencies, practically all of which have proved unsuccessful, apparently because of poor seed germination. As is the case with most native grasses, this species has had very little study with regard to viability of the seed and possible treatments for stimulation of germination. It is believed that information concerning such factors is essential before the practicability and economic feasibility of the use of this species in reseeding programs can be determined.

LITERATURE

Although literature on germination of seeds and methods of increasing and hastening germination is abundant, that dealing with *Oryzopsis hymenoides* seed is very rare.

The work of Huntamer[3] indicated a considerable variation in the viability of *Oryzopsis hymenoides* seed collected from different sections of the state of Washington. When the seeds were treated with concentrated sulfuric acid to weaken the indurate black seed coats, satisfactory germination was obtained from most collections. She concluded that acid treatment performed the same function as mechanical scarification in removing the seed coats which were believed to be the cause of low germination. She likewise concluded that since seeds soaked in water increased considerably in weight, intact seed coats

[1]Contribution from the Range Management Department, Utah Agricultural Experiment Station, Logan, Utah. Publication approved by the director May 24, 1938. Received for publication June 6, 1938.

[2]Range ecologist and Student, respectively.

[3]HUNTAMER, M. Z. Dormancy and delayed germination of *Oryzopsis hymenoides*. Unpublished thesis. Wash. State College. Pullman, Wash., 1934.

did not restrict water absorption, and hence their effect upon germination was one of mechanical resistance rather than of physiological restriction of the entrance of water.

PROCEDURE AND RESULTS

Seeds of *Oryzopsis hymenoides* were obtained from six areas in Utah varying ecologically from salt-desert winter range to high-mountain summer range. The seed varied in age from a few months to 6 years. Untreated samples of each collection were subjected to standard conditions for germination (Petri dish method) for periods of 1 month with entirely negative results. This indicated that the normal seeds were probably in a permanently dormant state and that the problem was not merely one of delayed germination. To determine the cause for this lack of germination, a number of examinations and experiments were instigated.

Several seeds were opened to determine the condition of the embryo within the seed coat. Less than half of the seeds of most collections so examined contained a developed embryo. The majority could not possibly germinate, since the black shell-like coat was entirely empty. An examination was made in an attempt to correlate size, color, and shape of the seed with development of the embryo. In the course of this examination a great variation in the size of individual seeds of *Oryzopsis hymenoides* was noted. In studying the effect of size upon development of the embryo the seed was separated into the following five size classes by a screen-type seed separator: (1) Very large, over 1/12-inch diameter; (2) large, under 1/12 but over 1/14-inch diameter; (3) medium, under 1/14 but over 1/15-inch diameter; (4) small, under 1/15 but over 1/18-inch diameter; and (5) very small, under 1/18-inch diameter.

Examination of these size classes separately indicated that size and general superficial appearances of the seed were no index to internal development. A definite correlation existed, however, between the weight of the seeds and their embryo development, developed seeds being notably heavier.

To separate full from empty seeds, tests were made on the tendency of the seeds to float or sink in various liquid media. The full seeds, being heavier, were found to settle in liquid much more readily than the empty lighter seeds. Alcohol was the most efficient separating liquid found. Very rarely did full seeds float on the surface of alcohol, while trials involving several thousand seeds showed 91% of the seeds which sunk immediately to be full. Water at room temperature was found almost as effective as alcohol in separating the seeds provided they remained in the water for a considerable time. Table 1 shows the percentage of seeds in various size classes which sunk in water after a brief churning.

From Table 1 it can be seen that practically all seeds sinking in water within 24 hours had developed embryos, whereas less than 50% of the original seed had developed embryos.

Germination tests were conducted to determine the viability of

TABLE 1.—*Percentage of Oryzopsis hymenoides seed which sunk in water after various time intervals and the percentage of these which contained developed embryos.*

Seed sample No.	No. of seeds	After 5 min.		After 24 hrs.		After 48 hrs.		After 72 hrs.	
		Sinking, %	Developed, %	Sinking, %	Developed, %	Sinking, %	Developed, %	Sinking, %	Developed, %
1	2,000	5.8	100	13.5	100	25.8	69.0	37.6	52.2
2	2,000	5.8	100	15.0	100	32.7	68.3	49.4	52.3
3	5,000	10.8	100	20.0	98.3	—	—	37.3	48.9

seeds sinking after various time intervals in water. Those sinking within 5 minutes were found to germinate an average of 22.5%. Those sinking after 5 minutes but within 24 hours germinated only 2%. No germination was obtained from seeds sinking after 24 hours. From these studies it is concluded that only seeds which sink in water within 5 minutes have a reasonable chance to grow. Those sinking after this period even though apparently well developed are, in general, not viable.

GERMINATION TESTS

After obtaining potentially viable seed by the above described method attempts were made to increase the germination of this seed by several artificial treatments. These germination tests were carried on in Petri dishes, using sterilized blotters and sterilized water. A number of chemical and physical treatments were tried, including concentrated sulfuric acid (36N), acetic acid (0.01N), dilute hydrochloric acid (0.001N), butyric acid (0.08N), thicurea (5 and 3% solutions), sodium carbonate, stratification in sand at 0° ± F, scarification, dry heat (80° C), alternate heat and cold, and removal of the seed coat by use of a knife.

Of these treatments only three resulted in any increase in germination, these three being concentrated sulfuric acid, scarification, and removal of the seed coat; however, the increase from scarification was too slight to be of practical value. It will be noted at once that all of these are methods which remove or weaken the seed coat; hence the cause of low germination in *Oryzopsis hymenoides* is presumably an impermeable or mechanically resistant seed coat.

The removal of this coat is undoubtedly brought about in nature by decay over a period of several months. Observations by the authors and by other workers indicate that a low germination may be obtained by allowing the seed to remain in soil for several months, during which time the coat rots away. Germination percentages of 1 to 4 have been obtained by the authors after 8 months from untreated seed planted in greenhouse flats. A much more rapid and complete germination, however, is desirable for range reseeding.

Seeds from which the coat had been mechanically removed by peeling with a knife germinated immediately, but this method is obviously impossible on a large scale. Further tests revealed the fact

that acid was equally efficient as a means of removing the seed coat and hence study was confined entirely to the acid treatment.

Experience with the use of sulfuric acid on Indian ricegrass very soon brought to light the fact that different sized seeds behaved very differently in acid, the smaller requiring much less time in acid than the larger in order to germinate. Hence, seed sinking in water within 5 minutes was separated into the five size classes previously described, and samples of each class were treated with 36N acid, just enough to cover the seeds, for time periods up to 150 minutes. Germination was usually effected within 3 days but occasional seeds required 15 to 20 days. Table 2 shows the average percentage germination that was obtained from each size class in Petri dishes.

TABLE 2.—*Average percentage of Oryzopsis hymenoides seed in five size classes which germinated after treatment with concentrated sulfuric acid for various time intervals.*

Size class	Minutes submerged in acid										
	0	15	30	45	60	75	90	105	120	135	150
Very small	0	16	42	21	1	0	0	0	0	0	0
Small	2	14	48	48	10	1	0	0	0	0	0
Medium	0	9	28	57	42	37	9	8	0	0	0
Large	0	0	3	28	42	42	38	44	3	3	0
Very large	0	0	0	5	46	62	51	45	15	11	1

It can be seen from Table 2 that little or no germination takes place until the seed coat has been destroyed by acid and that the seeds may remain in acid for a considerable time thereafter before their germination is greatly reduced. No single time period gives a maximum germination for all size classes and, hence, to obtain maximum germination a separation of the seed into size classes is essential. There is considerable doubt, however, as to the practicability of separation of seed on a large scale because of the time and difficulty involved. Owing to this limited possibility of separating seed into size classes, further tests were conducted on unseparated seeds to determine the loss of seed involved by omitting this operation.

Data presented in Table 2 indicate that, by separation into size class, a maximum average germination of about 50% can be obtained. Tests on unseparated seed gave a maximum germination of 26% after a 45-minute acid treatment. The average of several treatments of 45- and 60-minute durations was 22.5%. It is apparent, then, that reseeding programs in which seed was not separated would require over twice the quantity of seed required if a separation could be obtained. The advisability of separation could be determined for each seeding upon the basis of cost of seed and cost of separation into size classes.

Test plantings of acid-treated *Oryzopsis hymenoides* seed in soil under both greenhouse and nursery conditions brought to light the fact that the seedlings are very susceptible to fungal growth prior to emergence. Tests using seeds from which the coats had been mechani-

cally removed showed no great difference between the susceptibility of seedlings from acid-treated and non-treated seed. In unsterilized soil from 70 to 95% of the germinated seeds failed to emerge from the soil. Sterilization of the soil reduced this mortality to between 40 and 50%. Successful emergence from the soil could be obtained from only an average of 12 seeds from each hundred mixed size acid-treated seeds, whereas the same seed would give an average of 22.5% germination in a Petri dish. Numerous planting depths and soil textures were tried unsuccessfully in an attempt to increase the percentage of successful emergence. Practically all plants emerging from the soil became successfully established and could easily be grown to maturity in either greenhouse or nursery.

Germination tests on seeds that had been acid treated and stored for periods up to 6 months indicated that no harm resulted from dry storage of treated seed. Commercial seed companies might, therefore, treat large quantities and dispense them at later dates without loss.

DISCUSSION

By two simple treatments the germination of seed of *Oryzopsis hymenoides* can be raised to a point at which reseeding range land with this species has a reasonable opportunity to be successful Without treatment it is doubtful if reseeding will be successful. For example, seed from Tooele County, Utah, collected in 1935 gave, two years later, no germination without acid treatment; a maximum of 2% germination with acid treatment alone; 26% with segregation of the empty seed by water plus acid treatment; and 53% with segregation of the empty seed by water, separation into size classes, plus acid treatment. In soil, however, only 28% of the plants receiving this latter treatment could be expected to establish themselves successfully and to mature. Omitting the segregation into size classes resulted in emergence and establishment of only 13%. It would appear, therefore, that these treatments are absolutely essential to a reseeding program involving *Oryzopsis hymenoides*. It is believed that necessary equipment and materials could be secured at relatively low cost which would be adequate to large-scale treatment of seed.

SUMMARY

Oryzopsis hymenoides, though it is a widespread dominant throughout much of the western United States, has not been successfully used to reseed depleted areas.

Germination tests without seed treatment gave negative results which is believed to account for the failure in numerous reseeding programs.

Examination revealed that often over half the seeds lack a developed embryo and hence could never germinate. Undeveloped seeds can be practically removed by submerging the seed in water for 5 minutes. Most undeveloped seeds will float while most developed seeds will sink.

Numerous mechanical and chemical tests to increase the germination of developed seeds indicated that the firm seed coats prohibited

germination and that this could best be remedied by treating the seeds with concentrated sulfuric acid.

The period of time that seeds should be treated with acid varies with the size of seed, very small seeds requiring only 15 to 45 minutes and very large seeds requiring from 60 to 120 minutes. Therefore, separation of the seed into size classes is recommended for maximum success.

An average germination of 50% was attained by these treatments and slightly more than half of the seed germinating became successfully established and matured in soil.

It is concluded that these or similar seed treatments are essential to an economic reseeding program involving *Oryzopsis hymenoides*.

EFFECT OF WEATHER VARIANTS ON FIELD HARDENING OF WINTER WHEAT[1]

C. A. SUNESON AND GEORGE L. PELTIER[2]

IN the course of controlled freezing experiments at Lincoln, Nebr., extending over a 6-year period, certain data have accumulated that show wide seasonal and intraseasonal variations in field hardiness during the period of hardening development, i.e., November, December, and early January. These variations are of interest in themselves but also are of value in the analysis of weather influences on hardening under field conditions. The observed variations seem to be closely related to differences in radiation, temperature, day length, and precipitation. These weather factors, as well as others, have been considered in the literature concerning cold hardening of crop plants but usually in empirical experiments which have differed widely from actual field conditions.

REVIEW OF LITERATURE

The extensive literature on cold resistance and hardening has been reviewed by others, so only recent articles concerning one or more of the climatic variables herein considered are reviewed here.

Tysdal (16)[3] reported that in alfalfa shortening day-lengths had as great a hardening influence as lowering temperatures. The same author, as well as Saprygina (9), who employed spring wheats, found day-lengths approximating those of our shortest winter days most conducive to hardening.

Tysdal (16) also emphasized the importance of light intensity, especially under light deficiency conditions. A role for light might also be inferred from the work of the authors (13), wherein reduction in leaf area of winter wheats reduced hardiness; and from the work of Tumanov, *et al.* (15), who stated that carbohydrate exhaustion and not lack of aeration is responsible for killing of wheat under prolonged snow cover. Similarly, Salmon (8) showed hardiness differences in successive day and night freezing tests; and Dexter (2) mentioned the importance of accumulation and maintenance of high available carbohydrate reserves in the plant preliminary to efficient cold temperature hardening. Akerman (1) associated high sugar content with hardiness in winter wheats. The authors (12) have called attention to the superior conditioning effect of high temperatures, showing that greenhouse plants grown at 77° F had a greater capacity to harden under subsequent constant low temperatures than plants grown at 60° F.

The hardening influence of low temperatures is generally recognized. The authors (12) have shown that hardiness in winter wheat reaches a maximum after 3 weeks of exposure to constant temperatures between 29° and 35° F.

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[3]Numbers in parenthesis refer to "Literature Cited," p. 778.

Tysdal (16) considered a 2-week period of constant low temperature hardening as optimum for alfalfa, because in his earlier work a decline in hardiness after more than 3 weeks of such exposure had been shown.

Hill and Salmon (5) suggested that hardening by exposure to low temperatures was essential for the expression of normal relative hardiness of diverse wheat varieties; but Salmon (8) found it was not essential for a proper appraisal of rye varieties. Worzella (17) stated that he obtained maximum differentiation between wheat varieties when exposed for only 15 hours at 34° F but observed normal ranking of varieties in lots frozen direct from a warm greenhouse. The hardened condition in winter wheat may best be maintained by environments favoring the conservation of organic food reserves, according to Dexter (3). Both Salmon (8) and Tumanov (14) emphasized that acquired hardiness may be dissipated rapidly by exposure to warm temperatures.

Soil moisture acts as a buffer against sudden temperature changes, as was shown by both Salmon (8) and Tysdal (16); but Gruentuch (4) specifically pointed to high soil moisture as a factor reducing the degree of plant hardening. Newton (7) earlier found that a reduction in available water content within the plant was the most important quantitative change associated with hardiness. Scarth and Levitt (10) have shown that low temperatures or drought increase permeability of the cell membranes to water. They found permeability more closely correlated with hardening than any other physical character.

EXPERIMENTAL METHODS

In the experiments reported herein freezing tests were made at frequent but irregular intervals during the fall and into January of each of six seasons, 1930-31 to 1935-36, inclusive. In some years occasional tests were made in late January and later. Data were obtained from approximately 90,000 plants grown in 728 flats. Numerous varieties, some more hardy and others less hardy than the Nebraska 60 standard, were compared. The plants emerged about October 18 in all seasons. These plants were grown and frozen and their survival determined in a comparable manner each year. The technic has been described previously (11) and has been shown to approximate closely natural freezing with regard to both lethal temperatures and comparative varietal reaction.

The weather data presented were compiled from published records of the U. S. Weather Bureau Station at Lincoln, Nebr.

In this study the degree of hardening has been based upon the freezing temperature necessary to kill 40 to 60% of Nebraska 60 wheat plants. Nebraska 60 is intermediate in hardiness. It was found that when the freezing temperature used in the tests differed by more than 2° F above or below that required for killing 40 to 60% of Nebraska 60 plants, complete killing of some varieties or no killing of others usually occurred. Variations in the level of hardiness occurred from week to week and season to season, making it necessary to predict a new effective freezing temperature within the above range for each test. During the first season only three out of five experiments on the average were successful, the others being frozen either too lightly or too severely. In the last or sixth season, however, when radiation, temperature, day-length, and precipitation influences were recognized, a determination of effective freezing temperatures and satisfactory differentiation of varieties was secured in all experiments.

EXPERIMENTAL RESULTS

EFFECT OF SEASONAL VARIATIONS ON HARDENING

Freezing temperatures necessary to secure differential injury at indicated dates in each of six seasons to the end of January at Lincoln, Nebr., are shown in Table 1. Curves derived from these data to January 11 are shown in Fig. 1. The curves all start at approximately the same level early in November. Incidentally, this level is lower, i.e., the plants were more resistant to low temperatures than greenhouse plants that had been exposed to temperatures of approximately 32° F for 3 weeks (12) The identity of some of the factors responsible for this increased hardiness, it is hoped, will be made known to some extent from the present study.

TABLE 1.—*Freezing temperatures necessary to secure differential injury at indicated dates for each of six seasons, Lincoln, Nebr.*

1930–31		1931–32		1932–33		1933–34		1934–35		1935–36	
Date	°F	Date	°F	Date	°F	Date	°F	Date	°F	Date	°F
						November					
—	—	—	—	—	—	1	10	2	8	7	6
12	3	2	10	—	—	10	3	10	-1	—	—
16	0	16	7	14	1	17	4	12	-1	19	2
29	6	30	3	21	3	24	-6	17	-1	25	0
						December					
—	—	—	—	—	—	29	-8	22	-1	—	—
4	-8	14	-3	6	-11	13	-16	1	-6	5	-2
7	-8	—	—	9	-11	15	-16	5	-11	12	-8
19	-16	28	-4	—	—	—	—	14	-15	19	-10
—	—	—	—	—	—	—	—	17	-15	26	-11
						January					
2	-20	11	-4	4	-8	10	-24	8	-15	2	-13
5	-20	25	-4	24	-8	11	-24	31	-11	8	-13
9	-20	—	—	—	—	—	—	—	—	23	-11
—	—	—	—	—	—	—	—	—	—	30	-9

It will also be noted from Fig. 1 that there is a more or less regular decrease in the "effective freezing temperature" denoting an increase in hardiness as the season progresses up until approximately the end of the experiments in January. There is, however, a marked difference in seasons and there are certain fluctuations within seasons which require explanation. In the discussion which follows, an attempt is made to relate these to the weather factors that prevailed during the study. The data presented in Table 2 summarize certain meteorological factors believed to be related to hardening. Other weather factors are mentioned in the discussion of each season.

The highest levels of hardening occurred during the seasons of 1930–31 and 1933–34. In these seasons the total hours of sunshine and radiation were greater than in any of the four other seasons, except 1932–33, when, as will be shown later, practically all leaves

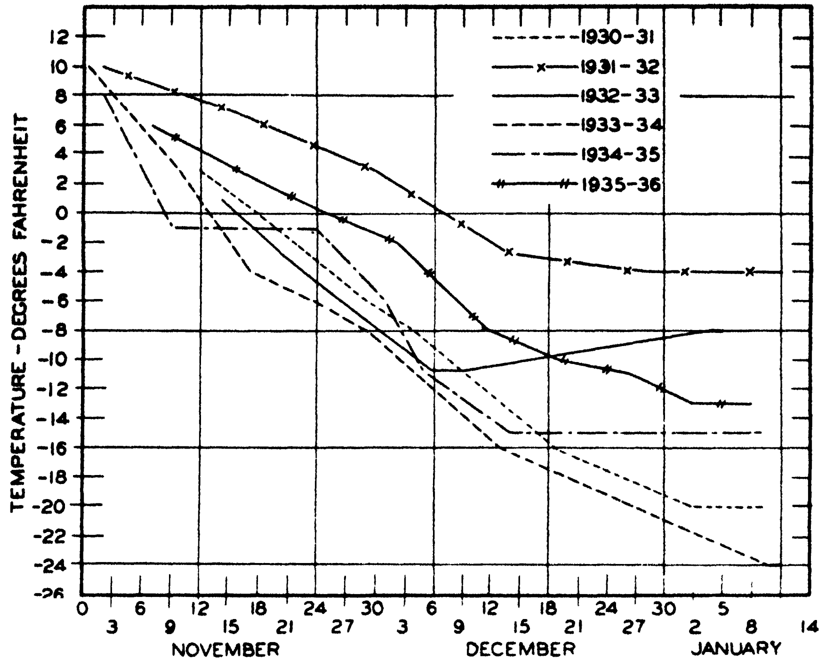

FIG. 1.—Observed progressive differences in the cold tolerance of field-grown winter wheat plants as measured by the freezing temperature required to kill 40 to 60% of Nebraska 60 wheat.

were killed on December 12. Mean temperatures were slightly above normal in consequence of rather high daily maxima. Temperatures in either season were never low enough to produce leaf injury. There were no periods of sustained snow cover. The consistent difference in hardiness between the 1930–31 curve and the one for 1933–34 seems to be a result of precipitation amounting to 3.3 inches during the period of November 17 to 20, 1930, since differences in other meterological factors were trivial.

Hardening developed least in 1931–32. In this season radiation was decidedly deficient after November 1, and rather frequent snow cover made the total radiation available to the plant even less. Precipitation was abnormally high during the entire period beginning November 9. Daily maximum temperatures averaged below those for 1930–31 and 1933–34, but minimum temperatures were higher and frosts less frequent. Only four frosts were recorded prior to November 23. During the entire period considered penetration of frost into the soil never exceeded 3 inches.

During the first half of November 1932–33 both temperatures and radiation were below normal, but during the rest of the month they were above normal. Soil moisture was more deficient than in any other season. By December 6 a rather high level of hardening for that date was noted. Lethal temperatures were recorded on December 12, but because of a light snow protection only the leaves were killed. Tests

TABLE 2.—*General record of meteorological factors believed to be related to observed hardiness differences in field-grown winter wheats, Lincoln, Nebr.*

Date	Temperature, °F					Days with minimum of 32° F or below	Radiation		Precipitation, inches	
	Av. daily maximum	Av. daily minimum	Mean	Absolute maximum	Absolute minimum		Daily average, gram calories	Total sunshine, Hours	Total	Snow
1930–31:										
Nov.	55.0	33.8	44.4	71	15	13	235	233	3.40	1.0
Dec.	39.6	24.1	31.8	64	14	28	156	152	0.12	0.1
Jan.	44.6	23.4	34.0	66	2	28	215	206	0.19	1.9
1931–32:										
Nov.	52.9	34.6	43.7	80	20	12	173	136	5.60	4.2
Dec.	43.6	30.4	37.0	57	18	18	129	125	2.26	6.6
Jan.	27.8	12.6	20.2	42	−9	31	189	129	1.92	14.5
1932–33:										
Nov.	48.5	27.0	37.8	67	8	22	216	136	0.04	0.1
Dec.	32.8	14.8	23.8	63	−14	29	185	158	0.81	6.8
Jan.	47.5	25.8	36.6	60	8	27	204	181	0.37	0.2
1933–34:										
Nov.	55.0	31.0	43.0	80	19	16	230	214	0.60	Trace
Dec.	43.2	22.5	32.8	70	4	24	167	165	1.05	0.5
Jan.	41.6	21.7	31.6	68	1	29	180	163	0.25	2.1
1934–35:										
Nov.	52.8	35.9	44.4	77	23	10	183	153	2.26	0.2
Dec.	33.8	19.3	26.6	47	−2	31	150	141	0.44	4.9
Jan.	36.2	17.8	27.0	58	−9	28	180	158	0.30	0.7
1935–36:										
Nov.	43.8	30.1	37.0	66	20	20	141	113	1.87	0.4
Dec.	37.1	22.1	29.6	56	0	27	131	126	0.30	1.8
Jan.	22.9	5.2	14.0	47	−19	31	186	152	1.64	19.3

in early January showed less hardiness than in early December. Radiation during December was exceptionally high and temperatures after the middle of the month were about average for that period. Some new growth was evident at the time of the early January tests. This new growth following severe defoliation, though not great, seems pertinent. Dexter (3) has shown loss of hardiness on production of new leaves after defoliation of plants hardened by low temperature.

The hardening trend during the 1934–35 season was the most variable of any season. High radiation and maximum temperature prior to and during the first week of November, tempered by several frosts after October 28, appeared to induce rapid hardening during the early part of the season. On the other hand, rain, low radiation, high temperatures, and absence of frosts combined to arrest hardening development completely during the period of November 10 to 22. For a 5-day period, beginning November 15, minimum temperatures did not fall below 43° F, and on one day the range was only 54° to 60°. After the November 22 test there was a very rapid acceleration in rate of hardening. Progressively lowering temperatures with small

daily variations and a conspicuous deficiency in radiation accompanied it. Beginning on November 27, and continuing for more than 5 weeks, frosts occurred each night. From November 28 until December 13 the maximum temperature did not exceed 35° F. This period of sustained low temperatures came at an unusually early date. During the first 3 weeks hardiness increased rapidly, but thereafter there was no increase despite persistence of cold weather until January. The authors (11) have shown that sustained low temperatures are effective for increasing hardiness over a period of only 3 weeks.

Conspicuously deficient radiation, frequent rainfall, and rather low temperatures were associated with the trends in hardiness during the early part of 1935–36. This season differed from 1931–32 in that the temperatures and precipitation were consistently lower. Effective radiation was apparently very similar because of less snow. Persistently low temperatures after the middle of December forced dormancy and resulted in progressively greater hardiness in each test over a 3-week period thereafter.

As previously mentioned, occasional tests were made in late January and later. These tests are mentioned here to support the belief that maximum development of hardiness was reached on or before January 11 in each season. Thus for the seasons 1934–35 and 1935–36, as shown in Table 1, tests late in January indicated that a decrease in hardiness had taken place. In the 1932–33 season, the maximum degree of hardiness was reached in December after which there was a decrease. Although not shown in Table 1, a freezing test was made February 8, 1932, which showed there had been a decline in hardiness as compared with the last preceding test made January 25. During 1930–31 no trials were made after January 9, and it is of course possible that the maximum degree of hardiness was not recorded that season. In 1933–34 there were no freezing tests between January 11 and March 9, during which period the effective freezing temperature changed from −24° to 2° F. Enough other tests were conducted during the late winter period of three of the seasons to confirm this 1934 trend and suggest that loss of hardiness under field conditions is continuous but variable in rate once it begins. A more complete record of progressive annual reductions in hardiness might have provided an interesting adjunct to the recent studies of Laude (6) on the transition from dormancy to active growth.

The hardening influence of low temperatures has long been recognized. Under field conditions this reaction does not seem to occur until both day and night temperatures remain too low for growth for several successive days. Such a change was readily recognized in all seasons except 1931–32 when very abnormal snow cover, temperature, and soil moisture conditions prevailed. Hardening from low temperatures may be initiated early, as in 1934–35, when sustained low temperatures began in late November or late, as in 1933–34, when low temperatures were not encountered until late December. In any case the resultant level of hardening seems to depend primarily upon the character of the weather preceding the cold period. Thus, in 1934–35 early incidence of sustained low temperatures probably found the plants less developed with respect to accumulation of organic reserves

than plants allowed a longer growing period the previous season. Similarly, in comparatively cold seasons, such as 1932–33 and 1935–36, when maximum hardiness would be expected if low temperatures are all important, actual hardening was relatively slight. Dexter (2) has pointed out that development and maintenance of a high available carbohydrate supply is essential in order that the cold-temperature hardening reaction may develop efficiently.

It was not possible to associate any increase in rate of hardening with differences in night temperature within the range of 10° to 35° F. High night temperatures appeared to arrest hardening, however, as shown during the period from November 10 to 22, 1934. This suggests that freezing temperatures at night, prior to the low temperature hardening reaction, may be important chiefly in restraining respiration during the long nights.

Recession in hardiness from the seasonal maximum may be abrupt under the influence of temperatures high enough to promote growth, as in 1932–33; or it may be delayed by sustained cold weather, as in 1934–35. Salmon (8) noted rapid loss of hardiness in cold-hardened plants when exposed to greenhouse temperatures.

High temperatures within the range usually observed in the field when acting in conjunction with high radiation exert a very favorable influence in preparing the plant for low-temperature hardening, as shown in 1930–31 and 1933–34. From November 1 to December 10, 1933, temperatures and radiation were at a 6-year maximum. During this 40-day period, temperatures of 32° F or lower were recorded only 22 times, and the lowest temperature was 15°. On the other hand, maximum temperatures exceeded 35° F on every day, and only on 9 of the 40 days were they below 45°. This, then, was a sustained period favorable for growth and assimilation, and not one of dormancy induced by low temperatures. Nevertheless, hardiness tests made December 13 to 15, 1933, showed greater hardening than resulted from all hardening influences (including sustained low temperatures) during any part of four other seasons. This was not the 1933–34 seasonal maximum, however, for sustained low temperatures thereafter resulted in further hardening, as indicated by the data from the freezing experiments of January 10 and 11, 1934.

The influence of day-length is perhaps the least apparent of the four climatic variables considered. The general progression toward maximum hardiness coincident with the period of shortest day-length is quite apparent in Fig. 1. Furthermore, this progression proceeded without decline of hardiness in spite of variable weather, until sustained low temperatures produced practical dormancy. It should also be noted that high radiation and temperatures while the days were becoming shorter, and before exposure to sustained low temperatures during 1930–31 and 1933–34, were perhaps an important factor in securing a high degree of hardening in those seasons. Conditions favorable to growth after sustained low-temperature hardening and in association with increasing day-lengths, however, seem to accelerate the loss of hardiness.

Hardening developed least during the excessively wet season of 1931–32. On the other hand, drought in 1932–33 probably contributed

to the high level of hardening noted on December 6 of that season. Snow cover may act to restrict hardening development if persistent as in 1931–32, or to insulate against low temperatures as in 1932–33 and 1935–36.

EFFECT OF REDUCED RADIATION ON HARDENING

It seemed desirable to verify the evidence for the relation of radiation to hardening by some special experiments designed for this purpose. Such experiments are reported in Table 3 in which the hardiness of normal field plants is compared with that of plants grown adjacent to them under a window screen cover. The experiments were conducted for 2 years. In each of them a significant reduction in cold resistance occurred as a result of growing under the screen.

TABLE 3.—*Comparative cold resistance of wheat plants grown in flats in the open and under a window screen as determined by exposure to controlled low temperature at successive dates.*

Treatment	Percentage of plants surviving								
	1934–35					1935–36			
	No. of tests on each date	Nov. 12	Dec. 1	Jan. 8	Average	No. of tests on each date	Nov. 19	Dec. 12	Average
No cover...	2	35	64	70	56	4	45	56	51
Covered with screen.	2	13	57	59	43	4	38	50	44

Table 4 presents results from a study in which wheat plants growing in flats in the field were covered with inverted empty flats for one or two consecutive daylight periods at intermittent dates. Each percentage survival figure given is an average of duplicate tests with eight varieties of wheat on each date. The experiments were conducted in 1935–36. The plants were covered only on clear days following at least one clear day and when temperatures were neither abnormally high nor low. While no measurements were made, it seems certain that the light leaking through the cracks in the inverted flats was at least equal to the radiation received on cloudy days. The differential cumulative treatments were applied over only a 33-day period, in October and November. The effects persisted for the duration of the experiment, however, being especially evident in the plants that received the least total radiation. Since other factors in the environment of these experiments were comparable it must be concluded that radiation is an important factor in field hardening.

DISCUSSION

Three winterhardiness stages under field conditions may be recognized from this work. The first embraces a period of accumulating organic reserves during which high radiation, high day temperatures,

TABLE 4.—*Comparative cold resistance of field-grown wheat plants covered for 1 and 2 clear-day periods as determined by exposure to controlled low temperatures at successive dates during 1935–36.*

Cumulative treatments	Percentage of plants surviving when frozen on							Percentage of total radiation during the period Oct. 28 to Nov. 30 available to plants frozen Dec. 5 to Jan. 22*
	November		December		January		Average	
	8	22	5	19	2	22		
No cover (continuous)	23	42	41	61	45	67	47	100
Covered (for 1 day periods) on Oct. 28, Nov 5, Nov. 12, and Nov 29	23	36	45	60	39	63	44	81
Covered (for 2 day periods) on Oct. 28 and 29, Nov 5 and 6, 12 and 13, 29 and 30	13	21	38	43	34	46	33	67

*Assumes total darkness from cover

scanty precipitation, and shortening day-lengths appear to be important. Normally, this influence is terminated in late December at Lincoln, Nebr. The second period is one of near dormancy induced by sustained low temperatures. Under this influence hardening seems always to reach its seasonal maximum in about 3 weeks. The third period is one of declining hardiness and progress toward active growth. This influence generally is first evident in late January. These three winterhardiness phases always occurred in the named sequence and only once during the season. Rate of development or recession varied greatly, depending on the weather.

It is apparent that field-hardening development is dependent upon a number of different and exceedingly variable climatic factors. This should be recognized in the design and interpretation of hardiness tests. More precise information on the nature and practical importance of weather hardening elements should be sought. The possible application of experiments such as this to a crop reporting service might well be considered.

SUMMARY

The observed seasonal progression and annual variations in the cold resistance of field-grown winter wheats during a 6-year period at Lincoln, Nebr., together with associated variations in the environment, were utilized in a study of the more obvious weather factors contributing to field hardening.

Two apparently distinct hardening stages were recognized in this work. During November and early December high daily temperature

maxima in conjunction with high radiation appeared to be most conducive to hardening. High temperatures with low radiation or high radiation with low temperatures were least effective. High temperatures and radiation were effective only in increasing hardening under the influence of shortening days, however. Rather xeric conditions also appeared to favor hardening. This suggests that maximum hardening at this period results from a radiation-temperature balance reacting with day-length and drought influences to give maximum accumulation of organic reserves.

Subsequent exposure to sustained low temperatures resulted in further progressive increases in hardiness for about 3 weeks. This low-temperature hardening reaction seemed always to effect maximum hardening for the season, the actual level apparently being determined by the efficiency and duration of the preceding growth-hardening stage.

Controlled experiments showing a reduction in hardiness under the influence of reduced light intensity are reported.

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THE RESPONSE OF SOYBEANS TO SOURCES OF NITROGEN IN THE FIELD[1]

W. B. ANDREWS[2]

IN inoculation tests with legumes in the field and in the greenhouse it is often desirable to compare yields with those obtained with combined nitrogen. Data on the response of soybeans to different sources of nitrogen will, therefore, be valuable in setting up tests of this kind. In a previous paper (2)[3] data were reported which show that 600 pounds of ammonium sulfate per acre did not reduce the amount of nitrogen fixed by soybean nodule bacteria.

Caldwell and Richardson (5) found that ammonium sulfate is not toxic to red clover when high quantities are added to the soil. The fact that legumes in mixtures containing grasses often do not do as well when combined nitrogen is applied has been interpreted differently by different investigators (2). Emphasis is placed upon the preference of legumes for nitrogen obtained through nodule bacteria on the one hand and the competition induced by the increased growth of grasses where combined nitrogen is applied, on the other hand.

Umbreit and Fred (14) concluded that, "Under conditions which result in a balanced carbohydrate-nitrogen relation in the soybean plant free nitrogen is the preferred form of nitrogen". A balanced carbohydrate-nitrogen relation "normally occurs under adequate sunlight of moderate intensity and in the presence of sufficient moisture and carbon dioxide". They concluded that, "If an excessive carbohydrate-nitrogen relation develops in the plants, the growth is favored by the presence of combined nitrogen".

Nitrate nitrogen has usually reduced the number of nodules and nitrogen fixation by legumes (6, 7, 8, 11, 12, 13), while small amounts of nitrates and ammonium sulfate have been reported to stimulate nodule production.

Allison and Ludwig (1) reviewed the literature on nodule reduction and decreased nitrogen fixation due to the application of high quantities of nitrogen, and from the data presented concluded that nitrogen reduced the root and nodule development through a reduction in the carbohydrate supply; whereas, Hopkins and Fred (8) and other workers from Wisconsin (6, 10, 14) placed emphasis on the relation between the carbohydrate supply and the functioning of the nodule bacteria. Andrews and Gieger (3) reported data on greenhouse work which show that nitrate of soda reduced the yield and nitrogen fixation by Austrian winter peas in the greenhouse.

Most of the work reported on the effect of nitrogenous fertilizers on legumes has been conducted in the greenhouse. The data reported in this paper were obtained in the field under natural growing conditions, and as a result, should be valuable in a study of the response of soybeans to combined nitrogen.

EXPERIMENTAL

Four sources of nitrogen were applied to soybeans in the field on Lufkin clay soil of pH 4.6 to 4.9. Three hundred pounds per acre of

[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication June 13, 1938.
[2]Associate Agronomist.
[3]Figures in parenthesis refer to "Literature Cited," p. 786.

superphosphate were applied to all plats. The limed plats received 400 pounds of dolomite per acre. The sources of nitrogen were applied at the following rates per acre: Ammonium sulfate, 600 pounds; nitrate of soda, 800 pounds; cyanamid, 571 pounds; and urea, 348 pounds. The plats consisted of one row, 3½ feet wide and 1/400 acre in size, and were replicated six times. Inoculated and uninoculated Biloxi soybean seed were planted May 17, 1937. The seed were covered lightly and the fertilizer and dolomite were put out about 2½ inches to one side of the seed, after which they were covered well. An excellent stand of soybeans was obtained and they were cultivated to keep down weeds. The soybeans were harvested in the small bean stage on September 13. Green weights were obtained for all plats, and they were converted into air-dry weights per acre. Samples for nitrogen determinations were obtained, dried, ground, and analyzed according to the methods of official agricultural chemists.

The standard error of the mean of each treatment was determined. The standard errors of the increases were calculated from paired yields.

EXPERIMENTAL RESULTS

The data on the effect of nitrogen source on the yield and nitrogen content of uninoculated and inoculated soybeans grown on limed and unlimed soil are reported in Table 1. The data are broken down to show the effects of the source of nitrogen, inoculation, and lime more plainly and are reported in Tables 2, 3, and 4.

TABLE 1.—*The effect of nitrogen source on the yield and nitrogen content of soybeans grown on limed and unlimed soil.*

Source of nitrogen	Unlimed		Limed	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
		Uninoculated		
$(NH_4)_2SO_4$	4,667±321	1.88±0.013	5,302±215	1.96±0.296
$NaNO_3$	5,407±289	2.37±0.068	4,982±817	2.31±0.196
Cyanamid	4,438±253	1.79±0.077	3,960±187	1.75±0.253
Urea	5,498±228	2.33±0.095	5,338±199	1.96±0.164
Check	3,140±341	1.29±0.119	3,378±256	1.60±0.121
		Inoculated		
$(NH_4)_2SO_4$	4,938±184	1.97±0.074	5,311±215	2.00±0.212
$NaNO_3$	5,820±243	2.28±0.101	5,740±243	2.10±0.054
Cyanamid	4,853±160	1.99±0.104	4,575±171	1.84±0.073
Urea	5,833±116	2.23±0.095	5,420±209	2.32±0.156
Check	3,653±291	1.73±0.086	3,802±397	1.63±0.063

EFFECT OF SOURCE OF NITROGEN ON YIELD AND NITROGEN CONTENT OF SOYBEANS

The yield of the soybeans receiving no nitrogen was 3,140±341, 3,378±256, 3,653±291, and 3,802±397 pounds per acre for the uninoculated unlimed, uninoculated limed, inoculated unlimed, and

TABLE 2.—*Increase in yield and nitrogen content of soybeans due to nitrogen source.*

Source of nitrogen	Unlimed		Limed	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
		Uninoculated		
$(NH_4)_2SO_4$	1,571±124	0.58±0.082	1,924±171	0.36±0.136
$NaNO_3$	2,266±236	1.07±0.143	1,686±270	0.71±0.147
Cyanamid	1,297±172	0.51±0.170	582±196	0.16±0.163
Urea	2,357±305	1.03±0.181	1,960±235	0.20±0.160
Check	3,140±341	1.29±0.119	3,378±256	1.60±0.121
		Inoculated		
$(NH_4)_2SO_4$	1,284±298	0.24±0.123	1,509±250	0.37±0.085
$NaNO_3$	2,166±267	0.54±0.073	1,977±318	0.48±0.055
Cyanamid	1,200±189	0.27±0.150	773±403	0.21±0.054
Urea	2,179±216	0.50±0.155	1,617±351	0.69±0.148
Check	3,653±291	1.73±0.086	380±397	1.63±0.063

TABLE 3.—*Increase or decrease in yield and nitrogen content of soybeans receiving nitrogen from different sources due to lime.*

Source of nitrogen	Uninoculated		Inoculated	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
$(NH_4)_2SO_4$	635±186	0.08±0.100	373±173	0.02±0.055
$NaNO_3$	120±183	0.07±0.083	-80±196	-0.16±0.085
Cyanamid	478±257	0.04±0.115	278±222	-0.15±0.107
Urea	160±285	-0.37±0.198	-413±146	0.09±0.231
Check	238±197	0.30±0.043	149±315	-0.11±0.078

TABLE 4.—*The effect of inoculation on the increase in yield and nitrogen content of soybeans receiving nitrogen from different sources.*

Source of nitrogen	Unlimed		Limed	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
$(NH_4)_2SO_4$	271±225	0.10±0.070	9±152	0.04±0.096
$NaNO_3$	413±170	0.02±0.149	453±99	-0.17±0.115
Cyanamid	415±88	0.20±0.135	615±212	0.08±0.048
Urea	336±197	0.10±0.137	82±104	0.35±0.290
Check	513±241	0.44±0.173	424±202	0.03±0.159

inoculated limed soil, respectively. The corresponding nitrogen contents were 1.29±0.119, 1.60±0.121, 1.73±0.086, and 1.63±0.063%.

Nitrate of soda increased the yield of the soybeans 2,266±236, 1,686±270, 2,166±267, and 1,977±318 pounds per acre on the uninoculated unlimed, uninoculated limed, inoculated unlimed, and in-

oculated limed soil, respectively. The corresponding nitrogen contents where nitrate of soda was applied were 2.37±0.068, 231±0.196, 2.28±0.101, and 2.10±0.054%. The corresponding increases in nitrogen content were 1.07±0.143, 0.71±0.147, 0.54±0.073, and 0.48±0.055%. These increases in yield and nitrogen content indicate that, under the conditions of this experiment, soybeans are able to utilize nitrate of soda efficiently.

The increases in yield where urea was used were just about the same as those for nitrate of soda. Likewise, the increases in nitrogen content due to the application of urea were about the same as those where nitrate of soda was used, except in the case of the uninoculated soybeans on the limed soil. In this case the increase in nitrogen content where nitrate of soda was applied is significantly greater than that obtained where urea was used.

With both the uninoculated and inoculated soybeans on the unlimed soil the increases in yield where ammonium sulfate and cyanamid were applied were only about two-thirds as large as those where urea and nitrate of soda were applied. The increases in nitrogen content where ammonium sulfate, and cyanamid were applied were only about half as large as where urea and nitrate of soda were applied. On the limed soil urea, nitrate of soda and ammonium sulfate made about the same increase in yield of inoculated and uninoculated soybeans and the increase produced by cyanamid was only about a third that obtained with the other sources. The increases in nitrogen content where cyanamid was applied to limed soil were 0.16±0.136, and 0.21±0.055% for uninoculated and inoculated soybeans, respectively. The addition of lime reduced the increase in yield obtained from the application of cyanamid to about half that obtained without lime. The lime added was only about two-thirds enough to neutralize the sulfate radical of the ammonium sulfate.

EFFECT OF LIME ON RESPONSE OF SOYBEANS TO SOURCES OF NITROGEN

The data in Table 3 show that lime increased slightly, but not significantly, the yield of the soybeans receiving no nitrogen on both the inoculated and uninoculated series. On the check plats lime increased the nitrogen content 0.30±0.045%. The nitrogen content of the soybeans receiving no treatment was 1.29±0.119%. Lime increased the yield of the uninoculated soybeans significantly in only one case and that was with ammonium sulfate. Lime decreased the yield of the soybeans in every case where nitrate of soda, urea, and cyanamid were applied. The decrease was significant only in the case of inoculated soybeans receiving urea. The only case where lime affected significantly the nitrogen content of the soybeans receiving nitrogen was in the uninoculated soybeans receiving urea. The nitrogen content of the latter was decreased 0.37±0.198%.

EFFECT OF INOCULATION ON RESPONSE OF SOYBEANS TO SOURCES OF NITROGEN

Without the addition of nitrogen, inoculation increased significantly the yield and nitrogen content of the soybeans on the unlimed soil

and the yield on the limed soil. The nitrogen content of the soybeans receiving inoculation on the limed soil was no greater than that of the soybeans receiving no inoculation. Inoculation did not increase the yield nor the nitrogen content significantly where ammonium sulfate and urea were applied. Inoculation increased the yield of the soybeans receiving nitrate of soda and cyanamid significantly on both the limed and the unlimed soil but had no significant affect on the nitrogen content.

RESPONSE OF STRAINS OF SOYBEAN ROOT NODULE BACTERIA TO LIME

Cowpeas had been grown on the soil on which these soybeans were grown on different years previous to the year the test was conducted. Soybeans had never been grown on this soil. Common lespedeza also volunteers in pastures on the soil type used in this experiment. When lime was added to the soil receiving no nitrogen, the nitrogen content of the soybeans was increased significantly; however, the increase in yield was not significant. Inoculation of the soybeans on the unlimed soil produced an increase in yield of 513 ± 241 pounds per acre and an increase of 0.44 ± 0.173 %in the nitrogen content. On the limed soil inoculation increased the yield of the soybeans 424 ± 202 pounds per acre but the nitrogen content was not changed. Evidently the strain of nodule bacteria applied was more efficient than the native strain on unlimed soil. These data are in harmony with those reported by Briscoe, Andrews, and Cowart (4) on the response of strains of soybean root nodule bacteria to lime.

RESPONSE OF SOYBEANS TO IONS ASSOCIATED WITH NITROGEN

Urea applied to the soil probably hydrolyzes to ammonium carbonate in a short time. The reaction is as follows: $CO(NH_2)_2 \pm 2H_2O \rightarrow (NH^4)_2CO_3$. Urea should therefore have practically the same affect on the yield and nitrogen content of soybeans as would ammonium carbonate. Since the soil is well supplied with CO_2, the results obtained with ammonium carbonate should be similar to those obtained from the addition of pure ammonia gas. In either case the soil colloids would absorb large quantities of ammonia and ammonium carbonate would exist in the soil solution for a short time at least. The application of urea to the soil for soybeans should therefore have the same influence on the yield and nitrogen content of soybeans as the application of pure ammonia.

Urea produced excellent increases in the yield and nitrogen content of soybeans. The results obtained with nitrate of soda were practically the same as those obtained with urea which indicates that the soybeans utilized the nitrate nitrogen of nitrate of soda and the amid nitrogen of urea equally well, and that there was apparently little, if any, influence exerted by the sodium of the nitrate of soda. However, the nitrogen content of the uninoculated soybeans on the unlimed soil receiving nitrate of soda was significantly greater than that of those receiving urea.

If soybeans respond to urea as if the nitrogen it contains were ammonium nitrogen, the difference between their response to urea

and to ammonium sulfate, $(NH_4)_2SO_4$, would seemingly be due to the sulfate radical. The sulfate radical reduced both the yield and the nitrogen content of the soybeans on the unlimed soil, but the harmful affects of the sulfate radical were overcome by the application of dolomite.

Cyanamid is a mixture of about 65% $CaCN_2$, about 15% $Ca(OH)_2$, and other constituents. The 571 pounds of cyanamid applied had about 46% more calcium than the dolomite which contained both calcium and magnesium. Even though the cyanamid radical produced excellent increases in yield and small increases in the nitrogen content of the soybeans, it was inferior in these respects to the ammonium and nitrate radicals for soybeans. The inferiority of the cyanamid group was increased on application of dolomite.

DISCUSSION

The work of Umbreit and Fred (14) shows that, "Under conditions which result in a balanced carbohydrate-nitrogen relation in the soybean plant free nitrogen is the preferred form of nitrogen". Under these conditions the soybean has a relatively high nitrogen content and nitrogen fixation goes on rapidly. Orcutt and Fred (10) pointed out that, "The percentage of nitrogen may be taken as a negative index of the carbohydrate level". A high nitrogen content indicates a low carbohydrate level and a low nitrogen content indicates a high carbohydrate level. Umbreit and Fred also concluded that, "Under conditions in which carbohydrate synthesis is restricted, the best development of soybeans is obtained in those plants which are furnished combined nitrogen".

Orcutt and Fred (10) concluded that an extremely high carbohydrate-nitrogen relation in the soybean plant inhibits nitrogen fixation. They obtained an extremely high carbohydrate-nitrogen relation when soybeans were grown in the sunlight in the summer. Shading brought about a change in the carbohydrate-nitrogen relation which was conducive to nitrogen fixation.

The percentage of nitrogen in the inoculated soybeans receiving no combined nitrogen was 1.63 and 1.73% on the unlimed and limed soil, respectively. On the basis of the nitrogen content indicating the carbohydrate level, this percentage of nitrogen indicates a high carbohydrate level. The high carbohydrate production is further indicated by the maximum yield produced which was nearly 3 tons per acre. In this test it is evident that the production of carbohydrates was nearly a maximum, and under these conditions nitrate of soda and urea increased the yield of the soybeans about a ton per acre. Ammonium sulfate and cyanamid were less effective than were the former two sources of nitrogen. On the unlimed soil nitrate of soda and urea increased the nitrogen content of the uninoculated soybeans more than 1%. With inoculated soybeans the increases in nitrogen content were around 0.5%. Cyanamid and ammonium sulphate were less effective in increasing the nitrogen content than were nitrate of soda and urea.

The data presented by the author in a previous paper (2) show that ammonium sulfate was very effective in increasing the yield and had only a small effect on the nitrogen content. The nitrogen content and yield of these soybeans indicate that carbohydrate production was at a relatively low level in this test.

An examination of the weather records for the two years in which these tests were conducted reveals a difference in rainfall during the growing season. The soybeans were planted and harvested at about the same time on each year. In 1933 the yield and nitrogen content of inoculated soybeans on limed soil was 2,013 pounds per acre and $2.20 \pm 0.021\%$ nitrogen where 75 pounds of ammonium sulfate were applied per acre. The data were not reported for the no-nitrogen treatment. The 75 pounds per acre of sulfate of ammonia increased the yield a small amount and probably had only a small effect on the nitrogen content. The season was very dry with only 0.84 inch of rainfall in June. Big rains fell on July 2, 9, and 10, with only occasional showers until August 29. In 1937 the yield and nitrogen content of the inoculated soybeans on limed soil without nitrogen treatment was 3,802 pounds per acre and $1.63 \pm 0.063\%$ nitrogen. In 1937 the rainfall was sufficient and well distributed. The yield and nitrogen content of the soybeans these two years indicate that carbohydrate production was very low during 1933 and that it approached a maximum during 1937. The high production of carbohydrates during 1937 is therefore attributed to the favorable growing season.

The energy requirement in nitrogen fixation was calculated from the data presented in the previous paper (2) to be about 50 pounds of soybean hay for 1 pound of nitrogen. The data presented in this paper could not be used to calculate the energy requirement of soybeans. Evidently, the energy requirement in nitrogen fixation can be calculated only from data which are obtained under conditions of limited carbohydrate production.

SUMMARY AND CONCLUSIONS

The response of soybeans to sources of nitrogen was determined in the field with inoculated and uninoculated Biloxi soybeans on limed and unlimed soil. Yields and nitrogen determinations were made. The yields and nitrogen content data indicate that the production of carbohydrates was at a high level. The data may be summarized as follows:

1. Nitrate of soda and urea were superior to ammonium sulfate and cyanamid in the production of soybeans and increased the nitrogen content of the soybeans on unlimed soil.
2. On limed soil ammonium sulfate was almost equal to urea and nitrate of soda as a source of nitrogen for soybeans.
3. Cyanamid was decidedly inferior to nitrate of soda, urea, and ammonium sulfate as a source of nitrogen for soybeans on limed soil.
4. Lime increased the yield of soybeans where ammonium sulfate was applied and decreased it where urea, cyanamid, and nitrate of soda were used.

5. Inoculation produced significant increases in yield of soybeans where nitrate of soda and cyanamid were used but did not where ammonium sulfate and urea were used.

6. Inoculation did not increase the nitrogen content of soybeans significantly where any source of nitrogen was used.

7. The native strain of soybean root nodule bacteria was in greater need of lime on the unlimed soil than the strain which was added.

8. The strain of soybean root nodule bacteria added was better suited to the soil conditions as they existed than was the native strain.

9. Carbohydrate production was much higher in a year of good distribution of rainfall than in a dry year, and conversely, the nitrogen content was much higher in the dry year when the soybeans obtained their nitrogen primarily from the soil and the root nodules.

10. On unlimed soil nitrate and amid nitrogen were superior to cyanamid for soybeans, and the sulfate radical of ammonium sulfate reduced the yield. Where dolomite was added, nitrate, amid, and ammonium nitrogen were superior to cyanamid nitrogen for soybeans.

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NOTE

A SIMPLE HEAD THRESHER

IN breeding work with small grains some method of threshing individual heads and panicles is indispensable. It is the purpose of this paper to describe the construction and operation of a cheap and efficient device designed for single-head threshing.

A motor-operated machine similar to that described by Kemp[1] was formerly used at the Georgia Experiment Station, but experience has shown that the grille type of thresher herein described is more efficient than cylinder types. Peto[2] has described a device for single-head threshing and reports excellent results from its use but the construction and operation of the apparatus described requires laboratory facilities and some little skill in metal work.

The thresher illustrated in Fig. 1 is of very simple construction and may be made from scrap materials. The metal seed-pan was made for use with the motor-driven cylinder thresher formerly used for threshing single heads, and the grille was constructed to fit the pan. A square cornered pie pan with sloping sides about 1 inch deep will serve for the seed-pan.

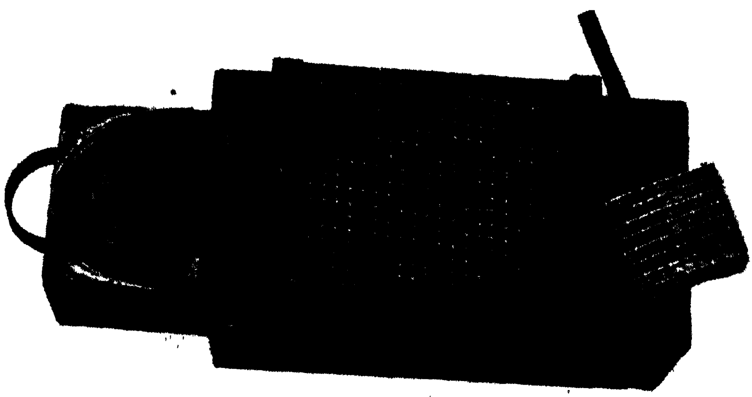

FIG. 1.—A head thresher. Wood construction is of 1-inch dressed material. The metal seed-pan (partly withdrawn) is scoop-shaped in its outline to facilitate the blowing out of chaff and sacking of seeds.

The grille is a section of galvanized hardware cloth of ⅜-inch mesh, mounted in a frame over the seed-pan, and three edges are covered with thin moulding. The scrubbing block is about 2½ by 2½ inches, and should be covered with the same type of wire cloth as that used for the grille. Reference to Fig. 1 will probably make further description unnecessary.

In operation, a spike or panicle of the grains is held on the wire screen by holding the culm in the left hand, while by a scrubbing motion of the block held in the right hand, the seeds and glumes from

[1]KEMP, H. J. Mechanical aids to crop experiments. Sci. Agr., 15:488–506, 1935.
[2]PETO, F. H. A simple method of head threshing. Sci. Agr., 15:825–826. 1935.

the spike or panicle are rubbed off the rachis and fall into the seed-pan. The seed-pan is then removed from the grille-box, and by a little judicious shaking and blowing, the chaff may be blown out, leaving the seeds to be poured into an envelope. Description of the actual operation of threshing is difficult, but after a few moment's practice the proper method will readily suggest itself to any operator.

The chief advantage of this device is in the fact that it will handle any of the small grains, sorghum, grain sorghum, and clovers, and is very efficient for preparing inoculum of bunt and oat smuts. The entire outfit may be conveniently sterilized in an autoclave. Timing tests show that 400 wheat heads may be threshed with this device in an hour and sealed in envelopes. This test does not account for time required for labeling. Experience has proved that this is by far the most efficient method of single-head threshing yet tried at the Georgia Station.—S. J. HADDEN, *Georgia Agricultural Experiment Station, Experiment, Georgia.*

AGRONOMIC AFFAIRS

FERTILIZER RECOMMENDATIONS FOR 1939

RECOMMENDATIONS for 1939 made by the Tobacco Research Committee made up of representatives for Virginia, North and South Carolina, Georgia, and Florida and the U. S. Department of Agriculture, are now available from the Chairman of the Committee, C. B. Williams, Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C.

NEWS ITEMS

ON JULY 1, P. H. DeHart, instructor in Agronomy, Virginia Polytechnic Institute, resigned to accept a position with the agricultural Adjustment Administration with headquarters in Blacksburg. Mr. M. S. Kipps formerly in charge of the experimental plat work in Blacksburg has been assigned to full time teaching and will assume the duties formerly carried by Mr. DeHart. Mr. Ed Shulkcum who has been working as a soil survey field man in Virginia since 1930 has accepted the position as Superintendent of experimental plat work at Blacksburg. Mr. E. M. Dunton, Assistant Agronomist, in charge of testing different sources of phosphates in Virginia has tendered his resignation effective September 1, to accept a fellowship in Cornell University where he expects to take graduate work leading towards a Ph. D. degree in soils. Mr. R. E. O'Brien, at present Assistant Agronomist at this station in charge of pasture investigations, will be transferred to assume duties formerly carried by Mr. Dunton. Dr. A. L. Grizzard, who has been Assistant Agronomist with the National Fertilizer Association at Washington since leaving this station in January 1937 will return to Blacksburg, as Associate Agronomist, in charge of pasture investigations and other experiment station duties.

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REPLACEMENT OF CALCIUM IN SOILS BY SODIUM FROM SYNTHETIC IRRIGATION WATER[1]

G. S. FRAPS AND J. F. FUDGE[2]

IRRIGATION waters in dry sections of the country frequently contain soluble salts. The formation of saline or alkali soils through the action of irrigation waters containing sodium salts is due to evaporation of the water without adequate leaching to prevent the accumulation of salts. The exchange of the calcium in the soil by sodium in the irrigation waters may cause the soil to run together so as to decrease percolation and increase the possibility of the accumulation of salts.

Kelley (2)[3] has pointed out that the action of the irrigation water upon the soil will depend upon the relative proportions of sodium and calcium in the water, and that wherever calcium is an important constituent of the accumulated soluble salts, the base exchange material is not greatly affected by the sodium salts, even though the concentration of soluble sodium salts be extremely high. Irrigation waters may contain sodium and calcium in the form of bicarbonates, chlorides, and sulfates in considerable quantities. Nitrates and magnesium salts are usually present in very small amounts, except in very exceptional cases. The experiments in this paper were undertaken to secure further information concerning the effect of different concentrations of sodium and calcium salts in irrigation waters upon the exchangeable calcium in the soil.

EXPERIMENTAL DATA

The differential energy of absorption of different ions has been well established. Gedroiz, in his pioneer work on base exchange showed that sodium is rather easily replaced by calcium, whereas calcium is by no means so easily replaced by sodium. This difference between cations has also been emphasized by Kelley (1). In the first experiments conducted, therefore, the relative energy of absorption or replacing activity of calcium and sodium were estimated by determining the proportions in which they replace hydrogen in the hydrogen-

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Texas. Published with the approval of the Director. Received for publication June 1, 1938.

[2]Chief, Division of Chemistry, and Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 796.

saturated exchange complex of a soil. Fifty grams of soil were shaken with 200 cc of N hydrochloric acid for 15 minutes. The soil was filtered off, leached with 200 cc of 0.2 N hydrochloric acid, and washed free of chlorides. The soil was again shaken with 200 cc of solution made up so that the total M.E. of salt in the solution equaled the exchange capacity of the 50 grams of soil. One-half of the salt was calcium chloride and the other half was sodium chloride. After shaking for 1 hour, the filtrate was analyzed for calcium and hydrogen ions which had been replaced from the exchange complex by sodium and calcium. The difference between the hydrogen ions found and decrease in calcium in solution was assumed to equal the quantity of sodium absorbed by the soil. Jenny (3) has proposed a similar method for measuring the relative absorbability of different ions.

The data secured are given in Table 1. Basicity is the quantity of acid, expressed as percentage of calcium carbonate, which was neutralized by the soil in digestion with 0.2 N nitric acid. From the data in Table 1, the relative exchange or replacing activities of calcium and sodium were estimated. Calcium and sodium together replaced about 20% of the total exchangeable hydrogen in the exchange complex. Of this quantity, calcium represented about 75% and sodium about 25%. The calcium was therefore about three times as active as the sodium in replacing the hydrogen. Even though the actual numerical value of the proportion might vary with different relative concentrations of sodium and calcium in solution, the data presented show that the energy of absorption or the replacing activity of calcium is several times as great as that of sodium.

TABLE 1.—*Relative replacement of hydrogen in an acid soil by calcium and sodium from solution.*

	Soil No. 12572, Crawford loam	Soil No. 18542, Wilson clay	Soil No. 7147, San Antonio silty clay loam	Soil No. 29427, Crockett clay loam	Soil No. 26079, Bell clay
Basicity, %	3.18	1.85	4.72	1.26	2.61
Total exchange capacity, M. E.	44.21	46.76	44.04	28.85	46.36
Calcium absorbed from solution M. E.	6.24	6.88	3.80	4.60	7.48
Hydrogen in solution, M. E	8.38	9.34	5.20	6.18	9.98
Hydrogen replaced in percentage of exchange capacity	19.0	20.0	11.8	21.4	21.5
Calcium absorbed in percentage of hydrogen replaced	74.5	73.6	73.1	74.4	74.9
Calcium absorbed in percentage of sodium absorbed	292	279	272	291	298
Sodium absorbed in percentage of hydrogen replaced	25.5	26.4	26.9	25.6	25.1

The replacement of calcium from the exchange complex of the soil by sodium in solutions of sodium chloride, sodium chloride with calcium chloride and sodium bicarbonate was next studied. Fifty grams

of soil were shaken 1 hour with 200 cc of water or of salt solution, filtered, and calcium determined in the filtrate. The quantity of calcium in solution with water was subtracted from that in the salt solution to give the net quantity of calcium replaced by the sodium. These data are given in Table 2. The quantity of calcium exchanged by a given salt solution did not increase regularly with increase in total exchange capacity of the soil but was largely determined by the character of the individual soil. For example, soils Nos. 18542 and 26079 have similar exchange capacities, but the quantities of calcium replaced from soil No. 26079 by sodium chloride were almost twice those replaced from soil No. 18542. The average quantity of calcium replaced by the various sodium chloride solutions was equivalent to

TABLE 2.—*Net increase (M. E.) in calcium content of solutions containing sodium chloride or sodium bicarbonate.*

Laboratory No.	Total exchange capacity 50 grams soil, M.E.	Salt used	Quantity (M. E.) of sodium salt used			
			2.5	5.0	7.5	10.0
29427, Crockett clay loam	14.4	NaCl	0.73	1.20	1.63	2.14
		NaCl+5 $CaCl_2$	0.16	0.26	0.62	0.86
20196, Abilene silty clay loam	14.8	NaCl	0.85	1.41	1.71	2.51
		NaCl+5 $CaCl_2$	0.45	0.78	0.98	1.15
		$NaHCO_3$	0.18	0.27	0.16	0.04
12584, Durant loam	14.9	NaCl	0.92	1.72	2.34	2.89
12582, Ellis clay	16.3	NaCl	0.76	1.22	1.72	2.40
		NaCl+5 $CaCl_2$	0.53	0.95	1.30	1.52
26075, Irving clay	18.4	NaCl	1.10	1.84	2.54	3.39
		NaCl+5 $CaCl_2$	0.55	1.13	1.34	1.64
		$NaHCO_3$	0.15	0.36	0.38	0.55
7147, San Antonio silty clay loam	22.0	NaCl	0.76	1.23	1.77	2.28
		NaCl+5 $CaCl_2$	0.50	0.93	1.22	1.43
12572, Crawford loam	22.1	NaCl	1.20	1.98	2.81	3.78
21067, Trinity clay	22.9	NaCl	0.81	1.37	1.96	2.75
		NaCl+5 $CaCl_2$	0.56	1.13	1.56	1.85
26079, Bell clay	23.2	NaCl	1.20	2.09	2.99	3.78
		NaCl+5 $CaCl_2$	0.38	1.04	1.42	1.54
		$NaHCO_3$	0.44	0.42	0.26	0.21
18542, Wilson clay	23.4	NaCl	0.53	1.05	1.51	2.02
		NaCl+5 $CaCl_2$	0.60	1.12	1.53	1.91
26095, Houston black clay	25.7	NaCl	1.26	2.21	3.14	4.12
		NaCl+5 $CaCl_2$	0.67	1.24	1.62	1.87
		$NaHCO_3$	0.40	0.30	0.03	0.03
Calcium replaced as percentage of sodium salt		NaCl	36	32	30	30
		NaCl+5 $CaCl_2$	19	19	17	15

about 30% of the salt in the original solutions. The addition of calcium chloride to the sodium chloride solutions reduced the quantity of calcium replaced by the sodium by about one-half, the decrease again varying with the individual soils. Net increases in the quantity of calcium in the filtrates after treatment of the soil with sodium bicarbonate solutions were quite small, and, in general, decreased with an increase in the concentration of the solutions. The sodium in the bicarbonate probably effects the exchange of some calcium, but this is precipitated as the carbonate and not removed from the soil.

Solutions containing both sodium chloride and sodium bicarbonate in different ratios gave net increases in calcium as shown in Table 3. The presence of the 1 M.E. of bicarbonate in the solution reduced the quantity of calcium in solution 52%, and 2 M.E. reduced it 44% when compared with the solution containing 5 M.E. of chloride alone. However, an increase in either sodium chloride or sodium bicarbonate resulted in a slight increase in the quantity of calcium in solution.

TABLE 3.—*Net increase (M. E.) in calcium content of solutions containing sodium chloride and sodium carbonate.*

Laboratory No.	Sodium chloride, M. E.	2	5	2	5	5
	Sodium bicarbonate, M. E.	2	2	1	1	0
20196	Abilene silty clay loam	0.36	0.64	0.30	0.52	1.41
26075	Irving clay	0.92	1.35	0.83	1.00	1.84
26079	Bell clay	0.87	1.42	0.72	1.18	2.09
26095	Houston black clay	0.88	1.34	0.75	0.99	2.21

The work with sodium chloride and sodium bicarbonate emphasizes the importance of the distinction between saline waters and those which are truly alkaline, containing relatively high concentrations of carbonates. When soils are irrigated with saline waters in which the sodium is combined in neutral salts, such as the chloride or the sulfate, the calcium remains in solution and equilibrium between the sodium in the irrigating water and the exchanged calcium is comparatively rapidly established and exchange of the calcium is reduced. With alkaline waters which contain carbonates, however, the calcium is precipitated, equilibrium is much more slowly established, and the sodium replaces a great deal more of the exchangeable calcium of the soil. This point has also been emphasized by Kelley (2).

In the preceding experiments, the soil was treated but once; whereas when irrigated, the soil is treated repeatedly with water containing the salts. The question arises as to whether or not the soil continues to lose calcium or if the soil finally reaches approximate equilibrium with the particular solution. In order to study this point, a number of soils were treated repeatedly with solutions similar to those used in the preceding experiment. After the first treatment, excess solution was removed from the soil by suction. An additional 200 cc of the original solution was added and the treatment repeated. A third treatment was made in the same way. The data secured are presented in Table 4. In the second treatment, the calcium replaced was equal

TABLE 4.—*Net increases (M.E.) in calcium content of solutions containing sodium chloride and calcium chloride.*

Laboratory No.	Series 1				Series 2					Increase due to single treatment, %
	5 M.E. $CaCl_2$+ NaCl M.E.	Treatment No. 1	Treatment No. 2	Treatment No. 3	1.67 M.E $CaCl_2$+ NaCl M.E.	Treatment No. 1	Treatment No. 2	Treatment No. 3	Total series 2	
12582, Ellis clay	2.5	0.53	0.02	0.00	0.83	0 23	0.11	-0.03	0.31	29
	5.0	0 95	0.24	0.11	1.67	0.41	0 19	0.05	0.65	46
	7.5	1.30	0.38	0 14	2.50	0.58	0.29	0.09	0.96	35
	10.0	1.52	0.46	0.20	3.33	0.76	0.36	0.08	1.20	27
7147, San Antonio silty clay loam	2.5	0.50	0.12	0 15	0.83	0.26	0.10	0 05	0.41	22
	5.0	0.93	0.29	0.21	1.67	0.46	0.17	0.12	0.75	24
	7.5	1.22	0.39	0.26	2.50	0.66	0.30	0.18	1.14	7
	10.0	1.40	0.71	0.22	3.33	0.90	0.40	0.21	1.51	23
21067, Trinity clay	2.5	0 56	0.23	0.08	0.83	0.23	0.10	0.06	0.39	43
	5.0	1.13	0.34	0.03	1.67	0.54	0.21	0.09	0.84	35
	7.5	1.56	0.59	0.15	2.50	0.76	0.32	0.17	1.25	25
	10.0	1.85	0.83	0.50	3.33	0.91	0.43	0.17	1.51	22
18542, Wilson clay	2.5	0.60	0 14	0.15	0.83	0.20	0.09	0.09	0.38	58
	5.0	1.12	0.25	0.16	1.67	0.40	0.29	0.15	0.84	33
	7.5	1.53	0.40	0.23	2.50	0.56	0.30	0.27	1.13	35
	10.0	1.91	0.65	0.34	3.33	0.75	0.38	0.31	1.44	33
Calcium replaced as percentage of sodium		19	6	3		26	12	6		31

to about one-third of that replaced by the first treatment, while in the third treatment, the replacement was less than one-fifth that of the first. These data indicate that the soil rapidly tends to reach a condition in which the further applications of a saline water has comparatively little additional effect.

Results of the preceding experiment brought up the question as to whether the effect of a given quantity of salt is the same when applied in one or in several treatments. Accordingly, a second series of solutions with one-third of the concentration of calcium chloride and sodium chloride used in the first series were made up. The quantity of calcium replaced in the single treatment with the more concentrated solution (series 1, treatment 1) was about one-fourth to one-third larger than when the same quantity of salts was applied in three treatments with a more dilute solution (series 2, total). However the relative replacement per unit of salt for a given treatment was higher with the more dilute solution (26%, 12%, and 6% compared with 19%, 6%, and 3%). The data show that less damage to a soil will result from a number of treatments with a dilute solution than from a single application of a more concentrated solution. They emphasize the importance of using irrigation water with a low concentration of salts.

In all of the preceding experiments, the quantity of calcium was kept constant while the quantity of sodium varied. One experiment was conducted in which the quantity of sodium was kept constant at 3.5 M.E., while the quantity of calcium was varied from 0 to 7.00 M.E. in the 200 cc of water. The net increases in calcium are given in Table 5. When the quantity of calcium chloride was increased from 0 to 7 M.E., the relative replacement of calcium by the sodium decreased from an average of 39% to 14%. These results agree with those reported in Table 2.

TABLE 5.—*Net increases (M. E.) in calcium content of solutions containing sodium chloride and varying quantities of calcium chloride.*

Laboratory No.	Sodium chloride, M. E.	3.50	3.50	3.50	3.50	3.50
	Calcium chloride, M.E.	0	1.75	3.50	5.25	7.00
12582	Ellis clay	1.32	1.10	0.90	0.79	0.75
7147	San Antonio silty clay loam	1.50	1.09	0.95	0.78	0.71
21067	Trinity clay	1.55	1.13	0.95	0.84	0.57
18542	Wilson clay	1.11	0.47	0.23	0.06	0.01
Net calcium as per cent of sodium		39	26	22	18	14

In the preceding work, the soil was brought into equilibrium with the solutions in static systems. In irrigation, the solution in contact with the soil may leach downward and be replaced by a new solution of the original concentration. In order to determine whether the conclusions reached from the work reported above were valid under such conditions, an experiment was set up in which 100 grams of soil in 1-inch glass tubes were leached with solutions containing 1.25 M.E. of calcium and 0 to 3.75 M.E. of sodium chloride. Successive 100-cc

portions of the solution coming through the soil were analyzed for calcium and the net change calculated. The results are given in Table 6. The average replacement of calcium, expressed with relation to the sodium in solution, was quite high (55%) in the first percolate, but the quantity in the succeeding percolates decreased rapidly to 31% in the second, 21% in the third, and 4% in the sixth. The results corroborate those secured in the earlier experiments tending to show that equilibrium is comparatively rapidly established, after which the further additions of the solution have little effect on the soil. The soils in this experiment were not allowed to come to dryness before the next addition of irrigation water was made. Had that been done, the results might have been different.

TABLE 6.—*Net increase (M. E.) in calcium content of successive lots of percolate caused by sodium chloride in the leaching solution.*

Laboratory No.	NaCl per 100 cc M. E.	Percolate No. 1	2	3	4	5	6
29427, Crockett clay loam	1.25	0.55	0.17	0.05	0.03	0.02	-0.03
	2.50	0.86	0.35	0.17	0.07	0.05	-0.02
	3.75	1.05	0.54	0.33	0.09	0.06	-0.01
12582, Ellis clay	1.25	1.09	0.38	0.23	0.12	0.05	0.04
	2.50	1.65	0.58	0.56	0.16	0.16	0.21
	3.75	2.49	0.94	0.77	0.23	0.15	0.06
7147, San Antonio silty clay loam	1.25	0.94	0.53	0.45	—	—	—
	2.50	1.54	1.19	0.62	—	—	—
	3.75	2.37	1.65	0.48	—	—	—
21067, Trinity clay	1.25	0.90	0.43	0.48	0.16	0.22	0.06
	2.50	1.86	0.99	0.99	0.69	0.60	0.25
	3.75	2.55	1.45	1.09	0.61	0.46	0.15
18542, Wilson clay	1.25	0.79	0.39	0.23	0.19	0.07	0.07
	2.50	1.23	0.77	0.56	0.38	0.21	0.16
	3.75	1.58	1.04	0.69	0.54	0.30	0.27
Calcium replaced as percentage of sodium		55	31	21	11	8	4

SUMMARY

Calcium chloride and sodium chloride, in equal equivalent concentration, and together equivalent to the exchangeable hydrogen in a hydrogen-saturated soil, replaced about 20% of the exchangeable hydrogen. Calcium absorbed represented about 75% of this quantity, leaving 25% for sodium. Calcium was thus three times as active as sodium in replacing hydrogen.

When 50 grams of soil were shaken with 200 cc of solutions containing 2.5, 5.0, 7.5, and 10.0 M.E. of sodium chloride, the average net increase in calcium content of the solutions was equivalent to 36, 32, 30, and 30%, respectively, of the sodium originally present. The addition of 5 M.E. of calcium chloride to the solutions caused a de-

crease in net calcium of about 50% of that found in the solutions containing sodium chloride alone. When sodium bicarbonate was used instead of sodium chloride, the net calcium was very small and decreased with an increase in bicarbonate concentration.

Replacement of calcium from soil receiving a second shaking with solutions containing sodium chloride and calcium chloride was equal to about one-third that in the first shaking, while that in the case of soil shaken three times was less than one-fifth of that in the first shaking. A single shaking with a concentrated solution replaced about one-third more calcium than was replaced by the same quantity of salt applied in three shakings.

Calcium replaced by solutions containing 3.5 M.E. of sodium chloride and 0, 1.75, 3.50, 5.25, and 7.00 M.E. of calcium chloride was equivalent to 39, 26, 22, 18, and 14%, respectively, of the sodium chloride present.

Calcium replaced by solutions containing 1.25 M.E. calcium chloride and varying quantities of sodium chloride per 100 cc in six successive percolates represented 55, 31, 21, 11, 8, and 4% of the sodium chloride originally present.

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NEW SMUT AND RUST RESISTANT OATS FROM MARKTON CROSSES[1]

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VARIETIES of oats highly resistant to stem rust have long been known. The same is true with respect to smut. Satisfactory resistance to crown rust, on the other hand, is a comparatively recent discovery. However, there are as yet no varieties in commercial production in which high resistance to all three diseases are combined and, further, except for Rainbow, there is no oat variety widely grown commercially that has marked resistance to more than one major oat disease. The adaptation of Rainbow is comparatively limited.

In 1927, a definitely planned hybridization program was started by the authors to produce oat varieties for the north central states which would have resistance to more than one of these diseases. This program has now been conducted for 12 years and numerous selections having resistance to two or more diseases have resulted. The exceptional promise of many of these selections seemingly justifies bringing them to the attention of plant breeders and the presentation of data regarding them.

THE PARENT VARIETIES

The varieties used in these crosses were Markton (C.I. 2053)[3], Iogold (C.I. 2329), Richland (Iowa 105, C.I. 787), Edkin (C.I. 2330), Rainbow (C.I. 2345), and Iowa 444 (C.I. 2331). All have been so fully

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[3]Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

described[4] and are so well known as to need only general descriptions here. They are classified morphologically as common yellow oats of *Avena sativa*, except Iowa 444, which is a common white oat, and all have the typical "sativa type" of floret separation and occasionally bear straight to twisted-geniculate awns, although Markton usually is awned and Rainbow usually is awnless.

Markton is a midseason oat; Rainbow and Iowa 444 are slightly earlier in maturity than are the typically midseason varieties such as Victory. Richland, Iogold, and Edkin are selections from Kherson, the well-known early oat of the Corn Belt.

Markton has so far proved highly resistant to the well-known races of both loose and covered smut (*Ustilago avenae* and *U. levis*) found in the United States. Richland is resistant to certain races of both the covered and loose oat smuts that attack Fulghum. Markton is extremely susceptible to all known races of both stem and crown rusts of oats (*Puccinia graminis avenae* and *P. coronata avenae*), whereas Richland, Iogold, and Rainbow are all resistant to the common physiologic races of stem rust (*P. graminis avenae*), Nos. 1, 2, 3, 5, and 7.[5] Although these varieties are susceptible to races 4, 6, 8, 9, and 10, the fact that races 2 and 5 probably constitute 98% of the stem rust that occurs in the United States has so far made their resistance highly effective as a protection against stem rust injury. Data from uniform rust nurseries[6] indicate that Edkin has considerable resistance to stem rust and possible resistance to some physiologic races of crown rust.

In addition to being resistant to stem rust Rainbow is resistant to certain physiologic races of crown rust (*Puccinia avenae coronata*) but completely susceptible to many other races of that disease. The writers have observed that Iowa 444 is heterozygous for resistance to certain races of both rusts.

Markton is well adapted to the western intermountain irrigated and dry-land areas. Rainbow is suited to the Red River Valley and elsewhere in North Dakota and the upper Mississippi Valley. Iowa 444 is productive in central and northern Iowa and has yielded comparatively well in northern Michigan. Richland (Iowa 105) and Iogold are grown extensively throughout the central and southern portions of the Corn Belt. Later maturing oats have proved better adapted farther north. Edkin, although approximating Iogold and Richland in yield in Iowa, is not superior to them and has never been distributed.

[4]STANTON, T. R., STEPHENS, D. E., and GAINES, E. F. Markton, an oat variety immune from covered smut. U. S. D. A. Circ. 324. 1924.

LEVINE, M. N., STAKMAN, E. C., and STANTON, T. R. Field studies on the rust resistance of oat varieties. U. S. D. A. Tech. Bul. 143. 1930.

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[5]LEVINE, M. N., and SMITH, D. C. Comparative reaction of oat varieties in the seedling and maturing stages to physiologic races of *Puccinia graminis avenae*, and the distribution of these races in the United States. Jour. Agr. Res., 55:713–729. 1937.

[6]See LEVINE, STAKMAN, and STANTON, footnote 4.

BREEDING METHODS

All crosses discussed in this paper were made in the greenhouse at the Arlington Experiment Farm, Arlington, Va. The following crosses were made in 1927: Richland (Iowa 105) × Markton (Cross No. X2712)[7], Markton × Iogold (No. X2737), and Edkin × Markton (No. X2738). In 1928, the crosses Iowa 444 × Markton (No. X2868) and Markton × Rainbow (No. X2871) were made. The heavy losses resulting from crown rust in 1927 prompted crossing Markton on varieties having resistance to this disease. In 1927–28, certain strains of Green Russian, such as Rainbow and Morota (C.I. 2344), and Iowa 444, offered the most promising source of resistance available, as such crown rust resistant varieties as Victoria and Bond were as yet unknown in the United States.

Although numerous exceptionally promising selections have resulted from the crosses of Markton with Rainbow and with Iogold, thus far no unusually worthy selections have evolved from the crosses with Richland or Edkin, and because of susceptibility to smut, all selections from the Iowa 444 cross were discarded by the end of 1934.

Some 5,000 selections have been made from progenies of the five crosses during the period from 1927 to 1937, and a few that have survived the pathological and the yield nursery tests have been advanced to replicated field plat experiments. Seedings were made on numerous experiment stations in 1936 and 1937.

Seedings have been made both in the greenhouse and in the field nursery. The objects of seeding in the greenhouse have been (a) to speed up the breeding program by growing an additional generation each year and (b) to determine with greater certainty the smut and rust reaction of the segregates so that the susceptible ones could be eliminated promptly. Moisture and temperature can be controlled somewhat in the greenhouse and control of these factors increases the chances of susceptible segregates becoming diseased.

Oats can be grown to perfection under irrigation at Aberdeen, Idaho. Under the late cool conditions there excellent crops of oats from May sowing have been obtained from seed grown in the greenhouse elsewhere and harvested in April. In consequence, alternate generations of many crosses have been grown in the greenhouse at Arlington, Va., and in the nursery at Aberdeen, Idaho.

In testing for smut susceptibility the seed of the selections has repeatedly been hulled and blackened with smut spores. This has served effectively in eliminating the highly susceptible selections in early generations and only resistant ones were retained. Early tests of the stem rust resistance were conducted in the greenhouse at Arlington but later tests have been made in the field at Ames, Iowa. In the greenhouse the adult plants were thoroughly wetted by a very fine spray of tap water and the rust spores, mixed with talc, were dusted over the plants. Some stem rust occurs naturally at Ames nearly every year and a few very effective natural epidemics have occurred. At all times the practice has been followed of eliminating stem rust susceptible strains whenever observed.

Crown-rust epidemics occurred naturally at Ames in 1935, 1936, and 1937 among selections from these crosses, but selections resistant to crown rust occurred only in the Markton × Rainbow cross. Data have been recorded on the reaction to crown rust of these selections in all three years and special attention

[7]All crosses discussed in this paper were made by F. A. Coffman, and the system used for numbering these crosses is as follows: e.g., X 2737 indicates a cross; the first two digits (27) indicates the year the cross was made; and the subsequent digits (37) the number of the cross of that particular year.

has been accorded selections that were homozygous for resistance. The type of resistance found in Rainbow and in the Markton × Rainbow crosses is not equal to that found in Victoria or Bond oats but has been sufficient for considerable protection against such crown rust as has occurred in recent years in the area to which these selections are likely to be adapted. Data also were obtained on the crown rust and stem rust resistance of many selections from an artificially inoculated nursery at Ames in 1935.

Promising selections from these crosses were obtained by both the pedigree and bulk nursery methods. Most of the selections from the Markton × Iogold and Richland × Markton crosses were secured from the pedigree cultures, but the bulk method was used exclusively in growing the early generations of the Markton × Rainbow and Edkin × Markton crosses. The bulk method may not be fully adequate in breeding for resistance to several diseases simultaneously.

HISTORY OF THE CROSSES

MARKTON × IOGOLD

The two seeds obtained of cross X2737, Markton × Iogold, were sown at Aberdeen, Idaho, in 1927. The seed produced on F_1 plants was divided, part being sent to the Brooklyn Botanic Garden, Brooklyn, N. Y., and part being planted in the greenhouse at Arlington Farm. From the lot planted at Arlington the F_2 generation was grown *en masse* in the greenhouse, the F_3 was grown at Aberdeen, Idaho, and the F_4 to F_{12} generations were grown at Ames, Iowa. Duplicate seedings of the F_9 generation were grown at Ames and at Aberdeen. Selections were made from F_4 and F_5 generation bulked material at Ames in 1930 and 1931. Re-selections were made at Aberdeen in 1934 and a few such re-selections were again re-selected at Ames in 1935. In 1937, 13 selections resulting as progenies of oat plants grown in the greenhouse at Arlington in 1927–28 remained.

Most of the promising selections from this cross have resulted from the F_2 seed sent to George M. Reed, Brooklyn, N. Y., in the winter of 1927–28. These selections were handled by the pedigree method and selections were made in F_2 and F_3 generations at Brooklyn[8], and in the F_4 generation at Lincoln, Nebr. In each of these three tests the seed was hulled and inoculated with smut before seeding.

Part of the F_5 lines were grown at Ames and part at Aberdeen in 1931, and all lines were grown at Ames for the first time in F_6 in 1932. Only six of these original lines were grown at Ames in 1937. Re-selections of this material were made at Ames, Arlington, or Aberdeen from 1932 to 1934, inclusive.

All of the more promising selections were derived as re-selections from the four lines Nos. 200, 307, 308, and 310. These re-selections were made at Aberdeen, Idaho, in F_8 in 1933. The latter three lines are progenies of the same F_2 plant and the last two of the same F_3 plant. Selections and re-selections numbering some 2,000 have been made from the Markton × Iogold cross. Probably not more than 20 of these selections will be grown in 1938.

[8]STANTON, T. R., REED, GEORGE M., and COFFMAN, F. A. Inheritance of resistance to loose smut and covered smut in some oat hybrids. Jour. Agr. Res., 48:1073-1083. 1934.

RICHLAND × MARKTON

The F_1 generation of the Richland × Markton cross, X2712, consisting of four plants, was grown at Aberdeen, Idaho, in 1927. The seed produced by the F_1 plants was divided, part being sown at the Brooklyn Botanic Garden, Brooklyn, N. Y., in the winter of 1927-28 and part in the nursery at Ames, Iowa, in 1928. Selections from each of these two lots remained in the tests in 1937. Many of these selections are from the former group and their history is almost identical with that of the Markton × Iogold selections which were handled by the pedigree method at Brooklyn. Strains grown in 1937 at Ames resulted from two selections made in the F_4 generation at Aberdeen in 1930. Re-selections from these lines were made in the F_8 generation in 1933 at Aberdeen. Probably only two or three of these re-selections will be sown in 1938.

The lot of seed sent to Ames in 1928 was grown *en masse* for five generations. From it 100 selections were made in the F_4 in 1930 and 87 in F_5 in 1931. Several of these have considerable promise. A few re-selections of some strains were made in 1934 at Aberdeen, Idaho. More than 1,100 selections and re-selections have been made from this cross and probably not more than 12 will be grown in 1938.

EDKIN × MARKTON

The Edkin × Markton cross made in the greenhouse at Arlington Farm and planted at Aberdeen, Idaho, in 1927 produced one F_1 plant. This cross was grown in bulk in the next four generations at Ames from 1928 to 1931. One hundred selections were made in the F_4 generation in 1930 and 82 in the F_5 generation in 1931. Only three of the selections made in 1931 remained in 1937 and of these two were then in the F_{11} generation and one in the F_{10}.

MARKTON × RAINBOW

The three seeds obtained from this cross were planted at Aberdeen, Idaho, in 1928. The F_2 generation was grown in the greenhouse at Arlington Farm in the winter of 1928-29, and the F_3 to F_5 generations were grown in bulk at Ames, Iowa, from 1929 to 1931. A total of 75 selections was made from the F_4 rows in 1930 and 139 from the F_5 rows in 1931. Numerous re-selections were made at Aberdeen and Arlington from 1932 to 1935 from the original selections made at Ames in 1930. A total of 179 such re-selections made at Aberdeen in 1934 was grown in the pathologic nursery at Ames in 1935, where artificially produced stem and crown rust epidemics proved many to be heterozygous for resistance. Re-selections were again made from such rows. Of the 179 re-selections 74 were grown in the F_{13} generation in 1937. Many of these selections, especially from line 708, are resistant to smut, stem rust, and certain races of crown rust, and produce excellent yields of grain of good quality. In addition, some of them have unusually stiff straw and have given strong indications of being resistant to heat and drought.

The group of 139 selections, made from the original bulked rod-row material in the F_5 generation in 1931, has not been re-selected extensively. These selections were grown in the F_6 to F_{11} generations at Ames, Iowa. Only eight were grown in 1937. Some of them are disease resistant and excellent in yield. A total of some 1,100 selections of this cross have been grown and in some cases re-selections have been made as many as five times between F_7 and F_{13} generations.

SMUT RESISTANCE OF SELECTIONS

Losses from the oat smuts (*Ustilago avenae* and *U. levis*) exceed those from any other disease of oats in the United States.[9] As a consequence, breeding for resistance to smut was first given attention in the present oat breeding program of this Division. Most segregates from which the present selections of the Richland × Markton and Markton × Iogold crosses have resulted were handled by the pedigree method in the F_2 and F_3 generations at Brooklyn Botanic Garden in 1928 and 1929. The F_4 generation of the former cross was grown in pedigree rows at Aberdeen, Idaho, and of the latter at Lincoln, Nebr., in 1930. In all three generations the kernels were hulled and then blackened with spores prior to seeding. Although these selections were free from smut in all three years, they were later found to be heterozygous for resistance in additional tests. Complete elimination of susceptible segregates in these lines had not been accomplished in the F_{13} generation. This may be due to (1) heterozygosity in strains selected, (2) the introduction of new smut races into the cultures, and (3) hybridity or impurity of the smut races used as inoculum. In the tests conducted at Ames, the smut spores employed were from collections made in Iowa, usually at Ames.

Selections from these same crosses made from plants grown *en masse* until the F_5 generation have, on testing, often proved only slightly less resistant than those handled by the pedigree method.

No selections were made from the Markton × Rainbow and Edkin × Markton crosses until the F_4 and F_5 generations. Since that time these strains have been tested repeatedly for smut resistance. The results obtained indicate that, on the average, these selections are only slightly less resistant than those of the Iogold and Richland crosses, which were handled by the pedigree method for the three successive early generations. There is no doubt, however, that more of the strains resulting from repeated re-selection are entirely free from smut than is the case among those selected only once or twice. Although immunity for smut resistance has rarely been obtained even by repeated selection, there seems ample reason for the belief that a practical degree of resistance to smut can be obtained with comparative ease. Data on the smut resistance of the oat selections from all crosses are presented in Table 1. This table does not include data in the F_2 to F_4 generations of strains grown by the pedigree method in which seed of all selections was smutted prior to seeding. Although a few smutted panicles have been observed in some tests, the data presented indicate that these selections, as compared with Iogold, are highly resistant to smut and there is little doubt but that all of these selections are extremely resistant to those smut races ordinarily found in the Corn Belt.

RUST RESISTANCE OF SELECTIONS

A study of the reaction of the selections from the several crosses to physiologic races 2 and 5 of stem rust of oats (*Puccinia graminis*

[9]Based on figures published in supplements of the Plant Disease Reporter, Bureau of Plant Industry, U. S. Dept. of Agriculture.

avenae) was initiated in 1930. The F_4 generation of the cross Markton × Iogold was grown in 1930 at Lincoln, Nebr., where a natural epidemic of stem rust occurred and selections of plants resistant to rust and smut were made by the senior writer. Among a large number of rust-resistant selections that year were the four plants from which the strains, 200, 307, 308, and 310, were derived. Table 2 presents data recorded on rust resistance of leading re-selections from these strains in tests conducted during the period 1931 to 1937, inclusive.

At Ames, during the period from 1931 to 1935, the practice of discarding all susceptible selections from these Markton crosses was followed. Some of the exceptional lines that were heterozygous for resistance were re-selected. Consequently, any selections from any of these crosses grown in the tests in 1937 had proved resistant to stem rust in numerous tests and resistant selections only are included in Table 2. In 1932–33 numerous selections were grown in the greenhouse at Arlington Farm under test of an artificially created epidemic of stem rust. Only rust-resistant selections were retained.

In 1933, many selections were grown in a breeding garden at Ames, again under test of an artificially induced rust epidemic, and, again, only resistant selections were retained. In the winter of 1933–34 a number of re-selections were grown in the greenhouse at Arlington. These were subjected to an artificial epidemic of stem rust, physiologic race 2. In 1934, the progeny of these plants were planted at Ames, but, because of extreme drought, the seed was lost. In 1935, 1936, and 1937 these selections were grown at Ames and elsewhere, and data obtained on their rust resistance are presented in Table 2. Prior to 1935 no data were recorded at Ames on the resistance to crown rust in any of these selections. In 1935 a serious naturally induced epidemic of crown rust occurred in Iowa, where, according to estimates, it caused a 20% reduction in yield. Many selections from the cross Markton × Rainbow proved highly resistant to crown rust at Ames that year, and the data obtained on the behavior of these selections are presented in Table 2. Further observations were made in 1936 and 1937. Fig. 1 shows the effect of both crown and stem rust on parental lines and certain selections from the Markton × Rainbow cross in Iowa in 1935. There seems little doubt that certain of these selections are as highly resistant to both stem and crown rust as is Rainbow and are likewise resistant to smut.

YIELD OF SELECTIONS

Disregarding their disease resistance, yield alone would make many of these selections of exceptional interest. Yield data obtained from tests in the Corn Belt are presented in Table 3 and those from other sections in Table 4.

The yielding ability of these selections as compared with the present standard oat varieties grown on the different stations in the Corn Belt is highly encouraging. Selections from the crosses Markton × Rainbow and Markton × Iogold have been especially high yielding in numerous tests. The high-yielding selections from the latter cross all trace back to four F_4 selections, Nos. 200, 307, 308, and 310, made at Lincoln in 1930. As a result of this close relationship these

TABLE 1.—*Reaction to smut of leading selections from four Markton oat crosses.*

Selection or variety	C. I. No.	Number of smutted plants in greenhouse tests at Arlington, Va.*		Number of smutted panicles per row										
				Aberdeen, Idaho†		Iowa**								
						Ames						Kanawha		
		1932–33‡	1933–34	1933‡	1934	1932‡	1933‡	1934§	1935	1936	1937*	1935	1936	1937*
Richland×Markton (×2712)														
524-5	—	0	0	0	0	0	0	0	0	0	0	—	0	0
-13	—	—	0	—	0	—	—	0	—	9	7	0	10	—
588-6	—	0	0	0	0	0	0	0	0	0	0	0	0	0
2411	3363	—	—	—	0	0	0	0	0	0	0	0	1	0
2444	3364	—	—	—	0	0	0	0	0	2	2	0	0	9
Markton×Iogold (×2737)														
200-4	—	0	0	0	0	0	0	0	0	1	0	0	0	0
-41481	—	—	—	—	—	—	—	0	0	0	3	—	0	0
-41486	3509	—	—	—	—	—	—	0	0	0	0	—	0	0
-41493	3510	—	—	—	—	—	—	0	0	1	0	—	0	0
-41499	3352	—	—	—	—	—	—	0	0	0	6	—	0	4
-41509	3353	—	—	—	—	—	—	0	0	1	3	—	0	1
307-41530	3512	0	—	0	—	0	0	0	0	0	0	—	0	0
-41534	—	—	—	—	—	—	—	—	0	0	0	—	0	0
-41541	3513	—	—	—	—	—	—	0	0	0	0	—	0	0
-41561	—	—	—	—	—	—	—	0	0	0	0	—	0	0
308-3	3237	0	0	0	0	0	0	0	0	0	0	0	0	0
-5	3239	—	0	—	0	—	—	0	0	0	—	0	0	—
-41568	3356	—	—	—	—	—	—	0	0	0	0	—	0	0
-41576	3357	—	—	—	—	—	—	0	0	0	0	—	0	0
-41580	3358	—	—	—	—	—	—	0	0	0	0	—	0	0
310-41626	—	0	—	0	—	0	0	0	0	0	0	—	0	—

Edkin × Markton (× 2738)															
2586	——	–	–	–	0	0	0	0	0	1	3	0	3	1
2588	3365	–	–	–	0	0	0	0	0	1	0	0	1	0
Markton × Rainbow (× 2871)															
668	3241	–	–	–	0	0	0	0	0	0	0	0	0	0
684–3	3341	0	0	0	0	0	0	0	0	0	0	0	0	0
–5	3342	–	0	–	0	–	–	0	0	1	0	0	0	0
–6	3244	–	0	–	0	–	–	0	0	0	0	0	0	0
–9	3343	–	0	–	0	–	–	0	0	0	2	0	0	0
–41913	——	–	–	–	–	–	–	0	0	0	0	–	0	5
–41944	3505	–	–	–	–	–	–	0	0	0	0	–	0	0
708–2	3346	0	0	0	0	0	0	0	0	1	5	0	0	0
–3	3247	–	0	–	0	–	–	0	0	0	4	0	0	7
–41974	——	–	–	–	–	–	–	0	0	0	8	–	0	1
–41978	3506	–	–	–	–	–	–	0	0	0	2	–	0	0
–41980	3507	–	–	–	–	–	–	0	0	0	2	–	0	0
–41983	3508	–	–	–	–	–	–	0	0	1	1	–	0	0
709	3348	–	–	–	0	0	0	0	0	0	3	0	0	0
1907	——	–	–	–	–	0	0	2	0	0	0	0	0	0
1943	3350	–	–	–	1	0	0	0	0	0	2	0	0	0
1965	3351	–	–	–	0	0	0	0	0	1	1	‖	0	0
1988	——	–	–	–	0	0	0	0	0	0	0	0	0	0
Markton	2053	–	0	0	2	–	0	0	0	0	0	–	–	0
Iogold	2329	7¶	5¶	2	49	‖	‖	20	‖	32	78	‖	17	61

*Tests made with hulled and inoculated seed.
**Except where noted, data from rod rows normally containing 400 to 500 panicles. Seed not inoculated with smut.
†Tests made with unhulled and inoculated seed sown in 5- to 8-foot rows.
‡Data from parent selections.
§Data from parent selections grown in 5-foot rows.
‖Smut present but no counts made.
¶Richland substituted for Iogold. Seven of 15 panicles smutted in 1933 and 5 of 15 in 1934.

TABLE 2.—*Reaction to rust of leading selections from four Markton oat crosses.*

Selection or variety	C. I. No.	Severity of infection						
		Stem rust				Crown rust		
		Type		Coefficient		Coefficient		
		Arlington, Va.		Ames, Iowa		Ames, Iowa		Kanawha, Iowa
		1932–33	1933–34	1936	1937	1935	1937	1935
			Richland×Markton (×2712)					
524-5	—	1	2	S*	—	—	+†	—
-13	—	—	2	S	—	—	+	—
588-6	—	1	3	0	1	—	50	—
2411	3363	—	—	0	1	—	45	—
2419	—	—	—	0	1	—	+	—
2444	3364	—	—	0	1	—	36	—
			Markton×Iogold (×2737)					
200-4	—	1	2	0	1	—	36	—
-9	—	—	2	0	1	—	36	—
-41481	—	—	—	0	1	—	36	—
-41486	3509	—	—	0	1	—	36	—
-41493	3510	—	—	0	1	—	40	—
-41499	3352	—	—	0	1	—	50	—
41509	3353	—	—	0	1	—	60	—
307-41530	3512	1	—	0	1	—	45	—
-41534	—	—	—	0	1	—	36	—
41541	3513	—	—	0	1	—	36	—
-41561	—	—	—	0	1	—	45	—
308-2	—	1	3	0	—	—	36	—
-3	3237	—	2	0	1	—	36	—
-5	3239	—	2	0	—	—	+	—
-41568	3356	—	—	0	1	—	36	—
-41578	3357	—	—	0	1	—	36	—
41580	3358	—	—	0	1	—	36	—
-41585	—	—	—	0	—	—	+	—
310-41626	—	1	—	0	—	—	+	—
			Edkin×Markton (×2738)					
2586	—	—	—	0	2	—	50	—
2588	—	—	—	0	1	—	50	—
			Markton×Rainbow (×2871)					
668	3241	—	—	0	1	12	16	6
684-3	3341	1	3	0	1	12	16	6
-5	3342	—	2	0	1	12	16	6
-6	3244	—	2	0	1	12	16	8
-9	3343	—	2	0	1	S	24	10
-41913	—	—	—	0	1	3	40	—
-41925	—	—	—	0	1	2	40	—
-41944	3505	—	—	0	1	3	16	—
708-2	3346	2	2	0	1	S	S	+
-3	3247	—	2	0	1	4	9	4
-41974	—	—	—	0	1	1	4	—
-41975	—	—	—	0	1	1	4	—
-41978	3506	—	—	0	1	3	6	—
-41980	3507	—	—	0	1	2	6	—

TABLE 2.—*Concluded.*

Selection or variety	C. I. No.	Severity of infection						
		Stem rust				Crown rust		
		Type		Coefficient		Coefficient		
		Arlington, Va.		Ames, Iowa		Ames, Iowa		Kanawha, Iowa
		1932-33	1933-34	1936	1937	1935	1937	1935
		Markton X Rainbow (X2871)						
708-41981	—	—	—	0	1	1	6	—
41983	3508	—	—	0	1	1	6	—
709	3348	—	—	0	1	+	32	+
1907	—	—	—	0	1	S	8	—
1943	3350	—	—	0	1	6	6	6
1965	3351	—	—	S	1	S	S	S
1976	—	—	—	0	1	S	6	—
1988	—	—	—	0	1	S	6	S
2016	3248	—	—	0	1	80	S	—
Markton	2053	—	—	10	40	90	80	70
Iogold	2329	—	2	0	1	80	50	40

*S = Segregating for resistance. Method of computing coefficient values is that used by Levine, Stakman, and Stanton (footnote 4, p. 798).
† + = Susceptible.

lines appear to be similar in yield although certain selections from the lines 200 and 308 may be slightly superior.

The Richard X Markton and Edkin X Markton crosses produced few exceptional selections. Selections Nos. 524-5 and 2444 are the best from the former cross. Selection 524-5 resulted from the pedigree method, whereas selection No. 2444 was produced by the bulk method of breeding.

Only the bulk method of breeding was followed with cross Edkin X Markton. Possibly the best yielding selection resulting from that cross is No. 2588, although selection No. 2586 appears only slightly less productive.

Selections from the Markton X Rainbow cross have been far superior in yield to those from any of the other crosses and they also are highly resistant to disease. Yield data obtained in the Corn Belt (Table 3) indicate that many of these selections are much superior in yield as well as in disease resistance to standard varieties. Most of the highest yielding selections from this cross trace back to the two lines, Nos. 684 and 708, which were selected in the F_4 generation from a bulk population of the cross growing at Ames, Iowa. The re-selections from these lines on which data are presented were made at Aberdeen, Idaho, in 1933. The strains grown in 10 or more tests which seem most promising include Nos. 668, 684-3, 684-5, 684-41944, 708-3, 709, and 1965. Selection No. 708-3 (C.I. 3247) has been exceptionally outstanding for yield in Iowa. It has averaged 93.5 bushels per acre for a 3-year period at Kanawha and 75.9 bushels at Ames.

TABLE 3.—*Yield in bushels per acre of leading selections from four Markton oat crosses grown at stations in the Corn Belt compared with standard varieties.*

Selection or variety	C. I. No.	Ames, Iowa L. C. Burnett H. C. Murphy							Kanawha, Iowa L. C. Burnett H. C. Murphy				Emmetsburg, Iowa L. C. Burnett	Lincoln, Nebraska T. A. Kiesselbach				Urbana, Illinois George H. Dungan			La Fayette, Indiana G. H. Cutler	Columbus, Ohio J. B. Park	Station years grown	Av. yield	Dev. from comp. av. of check varieties
		1932	1933	1934	1935	1936*	1937	Av.	1935	1936*	1937	Av.	1935	1935	1936	1937	Av.	1936	1937	Av.	1937	1937			
													Richland × Markton (× 2712)												
524–5	—	69.2†	39.0†	16.0†	37.0	67.0	88.4	64.1	—	97.0	—	97.0	—	—	—	—	—	—	—	—	—	—	4	72.4	+ 8.4
–13	—	—	—	—	40.5	74.2	86.2	67.0	50.5	74.0	—	62.3	40.5	—	—	—	—	—	—	—	70.9	—	7	62.4	− 1.2
588–6	—	74.6†	39.0†	20.5†	29.0	69.0	68.8	55.6	59.3	55.0	64.7	59.7	43.5	—	—	—	—	—	—	—	—	—	7	55.6	− 5.7
2411	3363	—	72.0	22.5	37.5	73.4	68.6	54.8	62.7	65.0	81.0	69.6	47.0	59.2	17.8	27.9	35.0	—	53.4	53.4	74.1	—	14	54.4	+ 1.1
2444	3364	—	72.0	16.5	44.3	76.8	80.4	58.0	63.8	62.7	87.0	71.2	49.0	50.4	21.7	34.7‡	35.6	—	57.3	57.3	76.0	—	14	56.6	+ 3.3
													Markton × Iogold (× 2737)												
200–4	—	78.8†	65.0†	9.0†	56.5	71.4	98.4	75.4	75.5	70.7	88.0	78.1	48.0	—	—	—	—	42.2	—	42.2	70.5	—	9	69.0	+ 6.9
–41481	—	—	—	—	60.0	71.4	91.4	74.3	—	69.3	86.7	78.0	—	—	—	—	—	—	—	—	—	—	5	75.8	+ 9.4
–41486	3509	—	—	—	68.0	73.0	95.8	78.9	—	72.3	88.0	80.2	—	—	—	—	—	—	—	—	—	—	5	79.4	+13.0
–41493	3510	—	—	—	67.0	72.6	94.8	78.1	—	67.3	89.0	78.2	—	—	—	—	—	—	—	—	—	—	5	78.1	+11.7
–41499	3352	—	—	—	53.0	72.0	95.0	73.3	—	73.0	84.7	78.9	—	—	—	31.9	31.9	—	52.0	52.0	—	37.3	8	62.4	+ 4.0
–41509	3353	—	—	—	64.0	70.8	97.6	77.5	—	79.3	101.3	90.3	—	—	—	33.2	33.2	—	56.7	56.7	—	38.7	8	67.7	+ 9.3
307–41530	3512	73.2†	70.0†	13.0†	69.0	64.6	102.6	78.7	—	80.7	92.0	86.4	—	—	—	—	—	—	—	—	—	—	5	81.8	+15.4
–41534	—	—	—	—	62.0	61.8	94.6	72.8	—	76.7	88.3	82.5	—	—	—	—	—	—	—	—	—	—	5	76.7	+10.3
–41541	3513	—	—	—	61.0	63.8	97.0	73.9	—	85.3	92.7	89.0	—	—	—	—	—	—	—	—	—	—	5	80.0	+13.6
–41561	—	—	—	—	52.0	80.0	90.6	74.2	—	73.0	81.7	77.4	—	—	—	—	—	—	—	—	—	—	5	75.5	+ 9.1
308–3	3237	75.4†	71.0†	11.0†	71.0	69.2	98.2	79.5	69.8	71.0	83.0	74.6	51.0	—	—	39.3	39.3	40.6	52.2	46.4	81.6	40.0	12	63.9	+ 6.0
–5	3239	—	—	—	54.8	66.8	—	60.8	72.8	73.3	– –	73.1	—	—	—	34.7	34.7	44.6	57.0	50.8	94.2	45.9	9	60.5	+ 4.4
–41568	3356	—	—	—	65.0	64.2	97.0	75.4	—	83.0	88.0	85.5	—	—	—	38.7	38.7	—	53.4	53.4	—	42.1	8	66.4	+ 8.0
–41576	3357	—	—	—	60.0	66.0	100.8	75.6	—	85.0	89.0	87.0	—	—	—	40.1	40.1	—	56.0	56.0	—	38.3	8	66.9	+ 8.5
–41580	3358	—	—	—	53.0	68.6	95.4	72.3	—	73.3	89.3	81.3	—	—	—	39.4	39.4	—	58.6	58.6	—	41.7	8	64.9	+ 6.5
310–41626	—	70.8†	60.0†	11.5†	52.0	73.0	100.8	75.3	—	70.0	—	70.0	—	—	—	—	—	—	—	—	—	—	4	74.0	+10.0
													Edkin × Markton (× 2738)												
2586	—	—	95.0	18.0	46.8	69.0	86.4	63.0	66.0	64.3	77.0	69.1	39.5	—	—	—	—	—	—	—	86.3	—	10	64.8	+ 6.4
2588	3365	—	95.0	14.5	50.3	69.8	88.2	63.6	67.3	90.7	78.0	78.7	42.0	—	—	—	—	—	—	—	82.7	—	10	67.9	+ 9.5

Markton ×Rainbow (×2871)

668	3241	69.0	79.0	19.5	59.0	76.6	101.0	67.4	83.6	81.0	99.7	88.1	58.0	—	—	—	—	44.6	56.0	50.3	—	34.0	13	66.2	+13.8
684–3	3341	66.4†	93.0†	16.5†	59.0	76.6	89.8	75.1	85.0	73.7	94.7	84.5	60.5	—	—	—	—	54.1	66.3	60.2	—	39.8	10	70.0	+13.3
–5	3342	—	—	—	56.0	76.0	85.0	72.3	94.0	76.7	91.7	87.5	60.5	—	—	35.2	35.2	52.9	61.6	57.3	—	34.9	11	65.9	+11.2
–6	3244	—	—	—	54.0	78.0	94.6	75.5	69.9	90.0	93.0	84.3	—	—	—	—	—	—	60.6	60.6	—	35.8	8	72.0	+10.5
–9	3343	—	—	—	60.0	75.2	85.0	73.4	80.8	75.3	101.3	85.8	58.5	—	—	—	—	53.8	64.4	59.1	—	—	9	72.7	+15.1
–41913	—	—	—	—	47.0	71.0	81.2	66.4	—	85.0	101.3	93.2	—	—	—	—	—	—	—	—	—	—	5	77.1	+10.7
–41944	3505	—	—	—	42.0	81.0	95.0	72.7	—	81.0	92.7	86.9	—	—	—	—	—	—	—	—	—	—	5	78.3	+11.9
708–2	3346	79.4†	67.0†	14.5†	53.5	66.0	93.8	71.1	62.5	79.3	79.3	73.7	39.0	—	—	36.2	36.2	40.8	46.7	43.8	—	36.2	11	57.6	+ 2.9
–3	3247	—	—	—	49.5	76.6	101.6	75.9	90.4	92.7	97.3	93.5	—	—	—	35.5	35.5	48.6	63.0	55.8	—	46.5	10	70.2	+13.7
–41974	—	—	—	—	41.0	90.0	99.2	76.7	—	75.0	88.0	81.5	—	—	—	—	—	—	—	—	—	—	5	78.6	+12.2
–41978	3506	—	—	—	34.0	84.0	105.0	74.3	—	69.0	97.7	83.4	—	—	—	—	—	—	—	—	—	—	5	77.9	+11.5
–41980	3507	—	—	—	46.0	83.0	110.4	79.8	—	71.0	93.7	82.4	—	—	—	—	—	—	—	—	—	—	5	80.8	+14.4
–41983	3508	—	—	—	58.0	69.6	95.6	74.4	—	76.3	88.3	82.3	—	—	—	37.2	37.2	—	49.7	49.7	—	39.7	8	64.3	+ 5.9
709	3348	78.4	77.0	17.5	54.5	71.2	93.6	65.4	58.3	82.7	90.3	77.1	45.0	—	—	—	—	46.4	45.5	46.0	—	—	12	63.4	+10.7
1907	—	—	—	17.5	54.0	72.0	85.2	57.2	96.0	63.0	—	79.5	55.0	47.0	22.2	37.4	35.5	—	—	—	—	—	10	54.9	+ 7.0
1943	3350	—	89.0	19.0	57.0	76.0	93.6	66.9	81.5	66.7	96.3	81.5	73.0	30.4	22.2	37.5	30.0	45.8	55.0	50.4	—	40.0	15	58.9	+ 9.5
1965	3351	—	69.0	18.0	72.0	74.2	89.4	64.5	81.8	76.0	90.0	82.6	63.0	—	—	—	—	49.5	59.7	54.6	—	43.5	12	65.5	+13.1
1988	—	—	71.0	16.5	56.3	67.0	88.4	59.8	81.8	68.0	—	74.9	43.0	36.8	21.1	30.9	29.6	—	—	—	—	—	11	52.8	+ 4.9
Markton	2053	—	88.0	21.5	28.9	—	—	46.1	40.3	—	—	40.3	31.0	—	—	31.3	31.3	—	—	—	—	—	6	40.2	— 0.1
Iogold§	2329	52.5	47.8	14.5	46.9	70.3	76.6	51.4	59.9	62.1	76.2	66.1	37.1	46.4	29.6	36.3	37.4	41.9	—	41.9	—	—	14	49.9	+ 0.4
Rainbow	2345	—	44.8§	15.2§	56.3	68.7	—	46.3	73.5	—	—	73.5	57.5	—	21.4	29.1	25.3	46.9	—	46.9	—	—	9	45.9	+ 3.7
Yield of check variety‖	—	52.5	47.8	14.5	46.9	70.3	76.6	51.4	59.9	62.1	76.2	66.1	37.1	46.4	29.6	35.5	37.2	37.8	51.2	44.5	92.2	48.6	17	52.1	
Average all selections exclusive of checks		73.7	79.9	18.0	53.8	72.5	92.6	—	74.0	75.6	89.3	—	50.9	44.8	21.0	35.6	—	47.0	56.3	—	79.5	39.7	—	—	—

*Yields from most selections are weighted average yields from more than one test

†Yield of parent selection from which re-selection was made. Data shown were omitted from all summary columns in table

‡Average of several rows.

§Average usually of many rows Consequently often not entirely comparable

‖The check variety at Ames, Kanawha, and Emmetsburg, Iowa, and Lincoln, Nebr., was Iogold; at Urbana, Ill, Sixty-Day, at LaFayette, Ind, Gopher, and at Columbus, Ohio, Franklin. Yields of checks are not always entirely comparable, being averages of all checks in the test.

TABLE 4.—*Yield in bushels per acre of leading selections from four Markton oat crosses grown on stations in northern and western United States compared with standard varieties.**

Selection or variety	C. I. No.	Fargo, North Dakota Glenn S. Smith 1935	1936	1937	Av.	Langdon, North Dakota Glenn S. Smith 1935	1936	1937	Av.	Madison, Wisconsin H. L. Shands 1936	1937	Av.	East Lansing, Mich. J. W. Thayer, Jr. 1937	Chatham, Michigan B. R. Churchill 1937	Ithaca, New York H. H. Love 1937	Corvallis, Oregon D. D. Hill 1937	Pendleton, Oregon J. F. Martin 1937	Station years grown	Av. yield	Dev. from comp. av. of check varieties
Richland × Markton (×2712)																				
2411	3363	—	—	—	—	—	—	—	—	—	61.7	61.7	—	—	—	—	—	1	61.7	+7.9
2444	3364	—	—	—	—	—	—	—	—	—	51.9	51.9	—	29.4	—	—	—	2	40.7	−1.0
Markton × Iogold (×2737)																				
200-4	—	—	—	—	—	—	—	—	—	28.9	—	28.9	—	—	—	—	—	1	28.9	−5.1
-41509	3353	—	—	—	—	—	—	—	—	—	51.6	51.6	69.9	—	—	—	—	2	60.8	+5.8
308-3	3237	—	—	—	—	—	—	—	—	35.3	56.2	45.8	—	—	—	57.6	48.4	4	49.4	−6.9
-5	3239	—	—	—	—	—	—	—	—	31.0	55.9	43.5	—	26.4	—	61.6	47.6	5	44.5	−6.4
-41568	3356	—	—	—	—	—	—	—	—	—	50.1	50.1	—	—	—	65.6	52.4	3	56.0	−7.7
-41576	3357	—	—	—	—	—	—	—	—	—	47.2	47.2	—	—	—	57.0	46.2	3	50.1	−13.6
-41580	3358	—	—	—	—	—	—	—	—	—	54.8	54.8	—	—	—	57.0	52.6	3	54.8	− 8.9
Edkin × Markton (×2738)																				
2588	3365	—	—	—	—	—	—	—	—	—	62.7	62.7	56.8	18.7	—	—	52.8	4	47.8	− 4.6
Markton × Rainbow (×2871)																				
668	3241	—	—	54.6	54.6	—	—	85.6	85.6	28.4	62.2	45.3	—	16.9	19.2	—	61.2	7	46.9	+ 2.5
684-3	3341	—	—	44.4	44.4	—	—	54.0	54.0	34.7	53.7	44.2	—	15.7	19.0	—	62.0	7	40.5	− 3.9
-5	3342	—	—	42.0	42.0	—	—	56.8	56.8	32.7	51.0	41.9	—	24.3	21.8	—	64.8	7	41.9	− 2.5
-6	3244	—	—	50.4	50.4	—	—	48.0	48.0	—	55.6	55.6	—	16.9	—	—	48.0	5	43.8	− 7.4
-9	3343	—	—	48.0	48.0	—	—	44.8	44.8	35.4	60.4	47.9	—	22.7	21.1	—	53.8	7	40.9	− 3.5
708-2	3346	—	—	32.8	32.8	—	—	20.8	20.8	34.5	47.5	41.0	51.6	22.3	34.5	—	56.2	8	37.5	− 8.4
-3	3247	—	—	51.6	51.6	—	—	46.0	46.0	33.9	49.6	41.8	63.4	34.7	40.4	—	67.8	8	48.4	+ 2.5
-41983	—	—	—	45.2	45.2	—	—	33.2	33.2	—	52.8	52.8	54.7	27.8	37.2	—	70.2	7	45.9	− 1.7
709	3348	—	—	57.6	57.6	—	—	—	—	34.9	49.1	42.0	60.7	32.4	32.9	—	56.6	7	46.3	+ 3.7
1907	—	—	15.7	43.2	29.5	—	15.5	74.8	45.2	—	—	—	—	—	—	—	—	4	37.3	+ 3.7
1943	3350	61.4	20.5	33.6	38.5	47.2	24.5	66.0	45.9	31.9	60.1	46.0	65.0	27.8	—	61.8	35.2	12	44.6	− 1.1
1965	3351	51.4	18.8	36.0	35.4	54.4	27.2	66.0	49.2	36.6	63.6	50.1	40.0	15.6	16.9	60.0	30.2	13	39.7	− 4.1
1988	—	50.2	19.5	57.0	42.2	40.4	19.6	60.0	40.0	—	—	—	—	—	—	—	—	6	41.1	+ 1.6
Markton	2053	—	—	—	—	—	—	—	—	—	—	—	—	—	—	73.0	70.0	2	71.5	+ 2.8
Iogold	2329	—	—	—	—	—	—	—	—	28.4	56.7	42.6	—	—	—	—	—	2	42.6	− 1.3
Rainbow	2345	54.5	15.1	30.4	33.3	48.1	19.0	68.8	45.3	31.0	—	31.0	—	—	—	60.6	69.8	9	44.1	− 1.3
Yield of check variety†		54.5	15.5	33.8	34.6	48.1	16.4	68.8	44.4	34.0	53.8	43.9	56.2	29.5	21.0	67.4	70.0	13	43.8	—
Average all selections exclusive of checks		54.3	18.6	45.9	—	47.3	21.7	54.7	—	33.2	54.9	—	57.8	23.7	27.0	60.1	53.3			

*Some of the selections were grown at Dickinson, N. Dak., from 1934 to 1937 inclusive. Only a few selections were grown in 1934 and 1935 and practically complete failures occurred in 1936 and 1937 due to drought and grasshoppers; consequently, no data from Dickinson are included.

†The check variety at Fargo and Langdon, N. Dak., was Rainbow; at Madison, Wis., State Pride; at East Lansing, Mich., Wolverine; at Chatham, Mich., Iowa 444; at Ithaca, N. Y., Cornellian; at Corvallis, Oreg., Victory; and at Pendleton, Oreg., Markton. Yields of checks are not always entirely comparable, being averages of all checks in the test.

These selections have been tested on stations outside the Corn Belt in fewer years. The data thus are less conclusive. Several selections yielding well in the Corn Belt have also been superior elsewhere. Selections from only the Markton × Rainbow cross have yielded well in sections where midseason oats are better adapted than are early oats. In tests conducted on stations to the north of the Corn Belt, selections from the Markton × Rainbow cross which seem superior are Nos. 668, 708–3, 709, 1907, and 1988. Several of these proved to be exceptional producers in tests in the Corn Belt also.

Markton, produced on the dry lands of eastern Oregon, has given ample proof of its drought and heat resistance in experiments in that area. Data obtained at Ames, Iowa, in 1934, the year of the great drought, indicate that at least a high degree of this ability probably was inherited by some of the selections, especially those from the Markton × Rainbow cross.

QUALITY OF SELECTIONS

Quality in oats has not been studied extensively in these tests, but its importance as indicated by test weight was recognized. Data recorded in 1935, 1936, and 1937 on weight per bushel of leading selec-

FIG. 1.—Result of both stem and crown rust infection on rows of parental lines and selections from the cross Markton × Rainbow at Ames, Iowa, in 1935. A, a selection from cross X311 (Markton × Iogold) × Carleton which proved susceptible to both rusts; B, Markton parent, susceptible to both rusts; C, Rainbow parent, resistant to both rusts; D, rows of selections resistant to both stem and crown rust.

tions of these crosses are presented in Table 5. The superiority of the Markton × Rainbow selections in this respect and the relationship between yield and test weight is evident. Test weights are particularly high among the selections from lines 684 and 708.

STRENGTH OF STRAW

Stiff straw, or the ability to resist lodging, is a major consideration in any oat breeding program. Frequently a stiff straw may determine the difference between success and failure of the crop. Observations on the standing ability of these selections were made at Ames and Kanawha, Iowa, in 1935, 1936, and 1937. Although most of these selections have given evidence of lodging resistance equal or superior to the nearest Iogold checks, only a few have remained standing in all tests. Selections which appear notable for stiff straw are as follows: Richland × Markton, selection 524–5; Markton × Iogold, selection 308–41576; and the Markton × Rainbow selections Nos. 708–2, 708–3, and 708–41974. The last three have resisted lodging in all tests, and selection No. 708–2 has a remarkably stiff straw for an oat so tall.

TABLE 5.—*Annual and average bushel weight of leading selections from four Markton oat crosses compared with Iogold.*

Selection or variety	C. I. No.	Bushel weight, lbs. Ames, Iowa 1936	Ames, Iowa 1937	Kanawha, Iowa 1935	Kanawha, Iowa 1936	Kanawha, Iowa 1937	Station years grown	Av. bu. wt., lbs.	Dev. from comp. av. of Iogold check, lbs.
				Richland×Markton (×2712)					
524–5	—	30.5	30.4	—	29.4	—	3	30.1	+5.3
–13	—	29.4	26.0	22.8	25.3	—	4	25.9	+2.2
588–6	—	26.2	27.2	19.9	19.9	26.3	5	23.9	–0.8
2411	3363	27.1	26.5	21.7	21.7	27.2	5	24.8	+0.1
2444	3364	26.7	28.9	20.7	23.2	28.7	5	25.6	+0.9
				Markton×Iogold (×2737)					
200–4	—	30.0	28.5	20.8	25.3	31.3	5	27.2	+2.5
–9	—	29.1	28.3	21.3	25.5	30.7	5	27.0	+2.3
–41481	—	29.3	29.3	—	24.7	30.3	4	28.4	+2.6
–41486	3509	30.4	27.1	—	26.3	30.0	4	28.5	+2.7
–41493	3510	29.6	28.2	—	26.0	29.1	4	28.2	+2.4
–41499	3352	29.1	27.0	—	25.6	27.8	4	27.4	+1.6
–41509	3353	28.7	26.5	—	26.0	29.4	4	27.7	+1.9
307–41530	3512	29.7	28.4	—	27.2	30.4	4	28.9	+3.1
–41534	—	28.6	27.8	—	26.7	28.7	4	28.0	+2.2
–41541	3513	28.9	27.1	—	27.1	30.1	4	28.3	+2.5
–41561	—	27.9	26.2	—	23.1	28.2	4	26.4	+0.6
308–2	—	30.0	27.2	20.8	25.5	30.7	5	26.8	+2.1
–3	3237	29.6	25.6	21.1	25.2	29.2	5	26.1	+1.4
–5	3239	28.7	—	23.2	24.5	—	3	25.5	+2.0
–41568	3356	28.9	26.6	—	26.5	29.5	4	27.9	+2.1
–41576	3357	29.3	30.1	—	27.2	31.8	4	29.6	+3.8
–41580	3358	29.4	27.2	—	26.5	30.4	4	28.4	+2.6
–41585	—	27.4	25.5	—	25.9	—	3	26.3	+1.5
310–41626	—	28.4	26.5	—	24.6	—	3	26.5	+1.7

TABLE 5.—*Concluded.*

Selection or variety	C. I. No.	Bushel weight, lbs.					Station years grown	Av. bu. wt., lbs.	Dev. from comp. av. of Iogold check, lbs.
		Ames, Iowa		Kanawha, Iowa					
		1936	1937	1935	1936	1937			
				Edkin×Markton (×2738)					
2586	—	29.8	26.8	19.3	23.8	29.0	5	25.7	+1.0
2588	3365	31.3	28.2	25.1	26.4	27.4	5	27.7	+3.0
				Markton×Rainbow (×2871)					
668	3241	29.5	29.5	23.8	24.6	32.2	5	27.9	+3.2
684-3	3341	31.4	31.2	27.3	27.9	34.1	5	30.4	+5.7
-5	3342	31.6	30.8	24.3	28.1	33.0	5	29.6	+4.9
-6	3244	29.0	30.6	28.4	28.2	33.9	5	30.0	+5.3
-9	3343	31.6	31.8	26.7	27.2	32.6	5	30.0	+5.3
-41913	—	29.3	29.1	—	27.8	31.9	4	29.5	+3.7
-41925	—	30.6	29.5	—	26.8	32.4	4	29.8	+4.0
-41944	3505	31.0	30.6	—	27.1	33.0	4	30.4	+4.6
708-2	3346	30.3	30.2	27.7	29.7	32.2	5	30.0	+5.3
-3	3247	30.9	30.8	26.6	30.2	33.3	5	30.4	+5.7
41974	—	30.2	31.2	—	28.2	33.8	4	30.9	+5.1
41975	—	29.2	30.9	—	27.8	33.7	4	30.4	+4.6
-41978	3506	32.0	32.0	—	27.2	33.8	4	31.3	+5.5
-41980	3507	30.7	30.2	—	28.3	33.2	4	30.6	+4.8
41981	—	29.5	31.9	—	27.5	—	3	29.6	+4.8
-41983	3508	30.7	30.7	—	29.0	33.1	4	30.9	+5.1
709	3348	30.6	30.9	20.6	28.1	31.7	5	28.4	+3.7
1907	—	29.9	31.3	—	23.5	—	3	28.2	+3.4
1943	3350	30.7	30.7	27.5	24.9	32.9	5	29.3	+4.6
1965	3351	30.1	29.0	28.2	25.5	31.8	5	28.9	+4.2
1976	—	27.4	28.1	—	21.7	—	3	25.7	+0.9
1988	—	26.5	28.5	22.1	22.8	—	4	25.0	+1.3
2016	—	29.5	—	25.1	22.5	—	3	25.7	+2.2
Markton	2053	—	—	17.5	—	—	1	17.5	−2.9
Iogold	2329	27.2*	24.3*	20.4*	22.9*	28.8*	5	24.7	±0.0
Rainbow	2345	—	—	27.0	—	—	1	27.0	+6.6
Average all strains exclusive of checks		29.5	28.9	23.7	26.0	31.0	–	—	—

*Average of all checks.

DISCUSSION

The hybrid progenies in these crosses were handled by (1) the bulk method and (2) the pedigree selection method.

The bulk method consisted of sowing a few rod rows of each cross with seed produced the previous year. Selections usually were made in the F_4, F_5, or F_6 generations on the basis of rust resistance and other desirable plant characters. Thereafter the progenies were handled by the pedigree method. The bulk method was used exclusively in growing the early generations of the Edkin × Markton and Markton × Rainbow crosses and partly with the Markton × Iogold and Richland × Markton crosses.

The pedigree method consisted of selecting in each generation after the first until the strains appeared to be uniform. This entailed con-

siderable recording of data on each selection in the early generations. The method was used largely in the Markton × Iogold and Richland × Markton crosses.

Numerous strains were discarded usually on the basis of readily observable deficiencies such as disease susceptibility, weak straw, etc. Strains which appeared especially good otherwise but which seemed to be heterozygous for plant characters or for disease resistance were re-selected and these re-selections were tested for yield and other agronomic characters.

High-yielding selections were derived from the Richland × Markton and Markton × Iogold crosses by both breeding methods, and by the bulk method from the Markton × Rainbow and Edkin × Markton crosses. Both methods have advantages as well as limitations. The pedigree method is preferable from all viewpoints if funds are available and experimental conditions permit, but the time and expense involved in an extensive breeding program may make it prohibitive. The bulk method permits a large number of hybrids to be grown in early generations without great expense. Selections can be made in more advanced generations as time and space become available, and in the meantime natural forces presumably are eliminating the less desirable strains.

The bulk method of breeding is only partly suited to breeding for disease resistance. In a program where breeding for resistance to several diseases is being conducted simultaneously, the problem is exceedingly complex. It is often difficult to obtain resistance to several diseases, together with favorable agronomic characters, in one individual. In such a program the bulk method is extremely valuable in early generations but must be dispensed with in later generations in favor of the refinements of pedigree methods. The writers have found it advantageous to select first for the major characters desired and later to re-select for homozygosity among the minor characters, as was done in the Markton × Rainbow cross.

Why so few high-yielding selections were obtained from the Richland × Markton cross is puzzling. Only 18 F_2 plants were selected in that group handled by the pedigree method. Possibly some desirable plants were not apparent in that generation. This might seem a plausible explanation were it not true that 187 selections were made from the bulk material and of these comparatively few have been exceptional yielders. Richland itself is a high-yielding oat, and exceedingly productive progenies have been selected from several other crosses in which Richland was a parent. It would therefore seem likely that this Richland × Markton cross was one in which the parents did not combine successfully, i.e., "nick" sufficiently well for the production of exceptionally high-yielding progenies. In the Markton × Rainbow cross the excellent characters of both parents were combined successfully and many high-yielding selections resulted.

The original F_4 plant of line No. 708 of the Markton × Rainbow cross was selected from a bulk population because of rust resistance. Tests of its progenies proved them to be resistant to loose and covered smut and to certain races of crown rust as well as stem rust.

They produce very high yields of grain of high test weight and have tall, exceptionally stiff straw. Some of the re-selections of line No. 708 have not lodged more than 2% in tests in which comparable Iogold checks frequently were lodged 100%. The notable ability of Markton to yield well under hot, droughty conditions probably was inherited by many of the selections from this cross as indicated by data obtained in 1934 at Ames. The combining to a marked degree of so many favorable characters in a single individual is unusual.

SUMMARY

A definite program was initiated in 1927 for the breeding of oat varieties for north-central United States with resistance to stem rust and smut. The smut-resistant variety, Markton, was crossed with the rust-resistant varieties, Richland, Iogold, Edkin, Iowa 444, and Rainbow. Some 5,000 selections and re-selections were tested. These selections have been subjected repeatedly to inoculation with spores of loose smut, covered smut, stem rust, and crown rust, in the greenhouse and field. Some of the resistant selections have been advanced to yield tests in plats.

Many of the selections have been found to be resistant to stem rust, covered smut, and loose smut during several seasons. Some of the selections from the Markton × Rainbow cross also were resistant to certain races of crown rust. This resistance should afford adequate protection against crown rust in the Corn Belt in certain years. However, they lack resistance to other races of crown rust, which may reduce their value in other years.

Selections from the crosses Markton × Rainbow and Markton × Iogold have proved the most promising, and some of them offer exceptional possibilities as agricultural varieties. Results indicate that many of these selections are superior in yield not only to the parent varieties but also to the standard varieties grown in the Corn Belt. Some of these selections also are superior to standard varieties in bushel weight. The bushel weight of many selections from the Markton × Rainbow cross has averaged 3 to 5 pounds more than that of Iogold grown under similar conditions. Many of the Markton × Rainbow selections have exceptionally stiff straw. Some have yielded comparatively well under extremely droughty conditions. Some of the highest yielding selections from this cross are resistant to the smuts and rusts and in addition have stiff straw and a high bushel weight.

CRABGRASS IN RELATION TO ARSENICALS[1]

F. A. WELTON AND J. C. CARROLL[2]

FOR many years statements pro and con have been made regarding the efficiency of lead arsenate as an agent for the control of crabgrass. Most of these statements were based on observation. Many observations by numerous people were possible because lead arsenate is in common use on golf courses and other places as an agent for the control of grubs. Observations at best, however, are not always dependable. If made under variable conditions or even if under comparable conditions but by different individuals, the possibility of arriving at erroneous conclusions is considerable.

To ascertain if lead arsenate has any merit as an agent for the control of crabgrass, experiments were conducted at the Ohio Agricultural Experiment Station during the period 1930–36, inclusive. Whether lead arsenate may prove to be an effective agent under all conditions remains to be determined. The results to date at Wooster, however, have been promising. It seemed advisable, therefore, at this time to make available the results thus far obtained in the hope that others might be stimulated to make trials to the end that its adaptation and usefulness on different types of soil and under varying conditions might be the more speedily determined. Moreover, the effectiveness of lead arsenate as an agent of control for the Japanese beetle is already accepted and since the presence of this pest is now (1938) recognized in Ohio, any information, particularly with reference to the aftereffect of the arsenates on the desirable turf grasses, is timely.

PRELIMINARY EXPERIMENT

As a preliminary test a single plat, 5 by 20 feet, on the Station campus was treated with lead arsenate July 25, 1930, at the rate of 35 pounds per 1,000 square feet. To facilitate even distribution, the arsenate was first mixed with compost, half-and-half. No injury was observable to the plants that year. In the following summer, 1931, which was a favorable season for crabgrass, it was early apparent that a relatively small number of plants was appearing on the treated plat. On September 14, after the plants had changed color and the identity of individuals, therefore, was the more easily discernable, a count showed a total of 75 on the 100 square feet, 23 of which were close to the margin, where in distributing the arsenate, the workers intuitively shy away lest some of the material be thrown beyond the bounds of the plat. Including the border plants, the reduction amounted to 94.6%, for on an equal area adjoining there were 1,350 plants. The number of crabgrass plants found on this plat in subsequent years, *viz.*, 1932, 1933, 1934, 1935, and 1936, was 52, 51, 14, 28, and 48, respectively. The control on a percentage basis for the same years in the order named was 98.2, 97.1, 97.6, 95.8, and 97.1.

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TIME AND RATE OF APPLICATION

1931–32 RESULTS

In the following season a second test was started and was so enlarged as to yield information regarding the time and rate at which the lead arsenate should be applied. The test was conducted in a private lawn in the community which was only fairly satisfactory for such a test because the stand of crabgrass plants was not dense and was less uniform on some parts than on others. The lead arsenate was applied at the rates of 2.5, 5, 10, 20, and 40 pounds per 1,000 square feet. Applications at these rates were made October 22 and December 11, 1931, and February 19, April 29, and June 6, 1932. The plats were 4 by 25 feet.

On account of lack of uniformity in stand of plants before treatment, no attempt was made to count the plants in the fall of 1932. From the lighter applications, 2.5 and 5 pounds, the effect, if any, was not discernible. From the heavier rates, 20 and 40 pounds, particularly the latter, however, the control was very marked. From the appearance of these plats the completeness of the elimination was satisfactory. The results from the application made on the first four dates were quite uniform.

1932–33 RESULTS

In the fall of 1932 and before the dying crabgrass had disappeared, an area was selected on the Station campus, all of which had been badly infested that year with crabgrass. Of course, it will be understood that over any large area there is usually considerable variation in the stand of such plants.

Lead arsenate was applied at the rates of 10, 15, 20, 25, 30, 35, and 40 pounds per 1,000 square feet on each of five dates *viz.*, October 31 and December 27, 1932, and February 15, April 21, and June 22, 1933. The plats were 5 by 10 feet and the various series joined each other. Counts were made in October 1933, 1934, and 1935, and the results, expressed in terms of plants per 1,000 square feet are given in Table 1.

These counts show that the lead arsenate was effective. The first year, 1933, the degree of control did not vary greatly with the first three dates of application. In general, the April application was somewhat less effective than the earlier ones. The June treatment was a complete failure, probably because the crabgrass was already up when the material was put on. In subsequent years, however, the June application also was effective as shown by the counts in the same table for the years 1934 and 1935.

The degree of control varied with the rate of application. With each increment of lead arsenate, up to and including 25 pounds, there was in general a progressive decrease in number of crabgrass plants. Beyond 25 pounds the effectiveness did not increase materially.

The higher counts in 1933 and 1935 than in 1934 were probably due to unusually dry weather in the early part of 1934. For the 8-week period, May 1 to June 25 inclusive, the time during which the

TABLE 1.—*Number of crabgrass plants per 1,000 square feet after treatment with lead arsenate at different times and rates, 1932–33.*

Time of application	Pounds of lead arsenate per 1,000 square feet								
	Check	10	15	20	25	30	35	40	Average of all rates
				October, 1933					
Oct., 1932..	15,080	1,920	.360	220	120	260	280	260	489
Dec., 1932..	15,880	4,340	980	620	340	240	280	160	994
Feb., 1933	15,200	640	360	520	200	300	140	160	331
Apr., 1933.	15,290	1,400	680	1,300	860	760	540	740	897
June, 1933 .	15,000	20,440	18,440	17,380	15,020	17,100	14,040	11,340	16,251
Average*	15,362	2,075	595	665	380	390	310	330	—
				October, 1934					
Oct., 1932.	1,320	280	160	20	20	0	20	80	83
Dec., 1932 .	1,600	1,000	320	0	20	40	20	0	200
Feb., 1933	1,440	200	40	20	0	0	0	20	40
Apr., 1933	1,760	100	40	40	0	0	20	20	31
June, 1933..	1,960	140	120	120	40	20	40	100	83
Average	1,616	344	136	40	16	12	20	44	—
				October, 1935					
Oct., 1932	3,250	220	280	60	40	0	20	120	106
Dec., 1932	2,470	1,960	860	180	20	0	60	0	440
Feb., 1933 .	2,550	260	20	20	0	20	0	0	46
Apr., 1933.	3,280	340	60	100	20	100	20	160	114
June, 1933 .	3,470	1,120	340	360	180	160	120	160	349
Average....	3,004	780	312	144	52	56	44	88	—

*Exclusive of June application.

majority of crabgrass seeds normally germinate in the latitude of Wooster, the rainfall in 1934 was 46.0 and 30.7% of that for the same period in 1933 and 1935, respectively.

1933–34 RESULTS

On another area of the Station campus also badly infested with crabgrass lead arsenate was applied in 1933–34 at the same rates as in the preceding year. In this test the dates of application were October 26 and December 20, 1933, and February 15, April 16, and June 11, 1934. The plats were 5 by 5 feet and the five series joined each other. In October 1934 and again in 1935 counts were made and the results, expressed in terms of plants per 1,000 square feet, are given in Table 2.

In this as in the three preceding tests, lead arsenate was effective in controlling crabgrass. The results as regards both time and rate of application were in general agreement with those obtained from the 1932–33 applications (Table 1). The generally lower counts in 1934 than in 1935 may have been due to more favorable seasonal conditions for the growth of crabgrass in the latter than in the former year. In October 1935, after the crabgrass plants were dead, they were re-

TABLE 2.—*Number of crabgrass plants per 1,000 square feet after treatment with lead arsenate at different times and rates, 1933–34.*

Time of application	Pounds of lead arsenate per 1,000 square feet								
	Check	10	15	20	25	30	35	40	Average of all rates
				October, 1934					
Oct., 1933	6,600	1,080	680	320	280	200	160	0	389
Dec., 1933	1,760	320	360	200	160	0	40	160	177
Feb., 1934	7,440	3,640	600	120	320	200	160	80	731
Apr., 1934	2,320	560	680	120	80	40	320	240	291
June, 1934	7,460	5,280	1,880	760	1,000	400	120	280	1,389
Average*	4,530	1,400	580	190	210	110	170	152	—
				October, 1935					
Oct., 1933	6,340	2,480	1,240	1,360	680	880	400	440	1,069
Dec., 1933	4,460	1,000	440	0	160	80	0	120	257
Feb., 1934	5,820	3,320	2,280	1,280	520	440	160	80	1,154
Apr., 1934	5,080	80	600	480	440	480	320	480	411
June, 1934	4,460	680	1,080	600	440	440	280	400	560
Average	5,232	1,512	1,128	744	448	464	232	304	—

*Exclusive of June application.

moved from each treated and from an adjoining untreated plat (5 by 5 feet) in several series. The effectiveness of the different rates of application in a fairly representative series, the one treated October 26, 1933, is shown in Fig. 1.

FIG. 1.—Quantity of crabgrass remaining on plats (5 by 5 feet) untreated (left) and treated with lead arsenate at the rates of 10, 15, 20, 25, 30, 35, and 40 pounds per 1,000 square feet.

MANNER OF APPLICATION

In the preceding tests the lead arsenate was first mixed with soil, half-and-half, in order to facilitate even distribution. To compare the efficiency of this with other methods, a test was started in the fall of 1932 in which the lead arsenate was applied in three different ways, namely, (1) as a mixture with soil, half-and-half; (2) as a dust; and

(3) as a spray. In each of these three tests the lead arsenate was applied at four different rates, namely, 5, 10, 20, and 40 pounds per 1,000 square feet. In the fall of 1933 and again in 1935 a count of the crabgrass plants was made on each of the treated plats and on an adjoining untreated plat.

The counts, recorded in Table 3, show no consistent superiority for any method in either year. Apparently, the important factor is that the material be thoroughly and evenly distributed.

TABLE 3.—*Manner of application of lead arsenate use at different rates.*

Pounds of lead arsenate per 1,000 sq. ft.	Number of plants per 1,000 square feet							
	1933				1935			
	Check	Mixture	Dust	Spray	Check	Mixture	Dust	Spray
5	—	3,180	3,140	2,400	—	1,360	1,240	500
10	—	600	2,000	1,000	—	260	880	780
20	—	380	360	520	—	320	160	440
40	—	160	100	300	—	0	60	60
Average of all rates	8,880	1,080	1,400	1,055	3,250	485	585	445

IN MIXTURE WITH VARIOUS PROPORTIONS OF SOIL

In order to determine if the efficiency in application of lead arsenate might be augmented through the use of increasing quantities of soil, an experiment was started in the fall of 1933 in which the lead arsenate was mixed with soil in the proportion of 1, 3, 5, 7, and 9 times its weight. The arsenate, mixed in these proportions, was applied at the rate of 5, 10, 20, and 40 pounds per 1,000 square feet. The plats were 5 by 5 feet. The crabgrass plants on these and on adjoining check plats were counted in the fall of 1934 and again in 1935. The counts are tabulated in Table 4.

The results reveal no consistent increase in degree of control as the proportion of soil was augmented. If the material is carefully distributed the proportion of soil is probably not important.

KINDS OF ARSENATE

By way of comparison with lead arsenate calcium arsenate was included in the test in the fall of 1933. The calcium arsenate was applied at the same time and rates and in the same manner as was the October treatment of lead arsenate. The two series of plats parallelled each other.

This test was repeated on the Station campus in 1935 and again in 1936. In the fall of 1935 manganese arsenate was included. The details of application of it were the same as for the other two arsenates. All three were applied November 20. In the fall of 1936 arsenic pentoxide was substituted for the manganese arsenate. The three materials were applied November 25. All the plats each year were the same size, 5 by 5 feet.

TABLE 4.—*Lead arsenate mixed with soil in different proportions and applied at different rates.*

Pounds of lead arsenate per 1,000 sq. ft.	Number of crabgrass plants per 1,000 sq. ft.					
	Check	1 to 1	1 to 3	1 to 5	1 to 7	1 to 9
			1934			
5	7,280	4,560	2,760	5,480	7,080	4,360
10	5,720	960	960	800	1,400	1,160
20	4,180	280	80	0	40	40
40	2,600	000	80	40	40	40
Average	4,945	1,450	970	1,580	2,140	1,400
			1935			
5	7,340	7,200	4,960	7,160	6,280	4,880
10	7,000	1,840	760	1,240	1,520	1,160
20	4,980	480	80	120	0	0
40	3,540	80	40	40	40	40
Average	5,715	2,400	1,460	2,140	1,960	1,520

The number of crabgrass plants in each test a year following treatment and the 3-year average of the calcium and lead arsenates are shown in Table 5.

TABLE 5.—*Number of crabgrass plants per 1,000 square feet after treatment with different arsenates.*

Kinds	Pounds of arsenate per 1,000 sq. ft.								
	Check	5	10	15	20	25	30	35	40
			October, 1934 (Treated in 1933)						
Calcium arsenate	6,220	—	1,280	160	200	40	0	0	0
Lead arsenate	6,600	—	1,080	680	320	280	200	160	0
			October, 1936 (Treated in 1935)						
Calcium arsenate	14,780	1,880	200	120	0	0	—	—	—
Lead arsenate	13,660	3,280	1,560	2,480	1,040	880	—	—	—
Manganese arsenate	12,660	2,400	320	160	120	0	—	—	—
			October, 1937 (Treated in 1936)						
Calcium arsenate	7,940	3,760	3,000	2,000	640	680	—	—	—
Lead arsenate	6,520	6,640	4,320	2,040	1,240	1,160	—	—	—
Arsenic pentoxide*	7,480	4,760	3,160	1,240	520	360	—	—	—
			3-year Average, 1934–37						
Calcium arsenate	9,647	—	1,493	760	280	240	—	—	—
Lead arsenate	8,927	—	2,320	1,733	867	773	—	—	—

*Quantities applied equivalent in arsenic to that contained in the lead arsenate.

From these results the conclusion may be drawn that calcium arsenate, pound for pound, is more effective than lead arsenate as an agent for the control of crabgrass. Unfortunately, at the heavier rates, it injured severely and even killed much of the grass. The dam-

age, however, did not become apparent until about a year later. The highest rate of application at which no killing was observable 2 years after application was 15 pounds per 1,000 square feet. At this rate of application, the control was as good as from the use of 25 pounds of lead arsenate.

The 1-year test with manganese arsenate indicated that it is somewhat less effective than calcium but more effective than lead arsenate.

Arsenic pentoxide was effective, but in the heavier rates which were required to give satisfactory control it killed all the grass.

AFTEREFFECT OF ARSENATES

All the arsenates discolored the grass somewhat. The discoloration, however, did not become apparent until a year or more after application and was most noticeable in winter. The lead arsenate, even in the larger quantities, did not cause the development of any bare spots in the turf. On the other hand, calcium arsenate, in quantities exceeding 15 pounds per 1,000 square feet burned severely and even killed much of the grass.

That the discoloration was accompanied by a reduction in growth of grass, at least in the case of the lead arsenate, was shown by the growth of grass obtained on them in 1934 and again in 1935. In these years the green clippings from the plats treated in October, December, and February, 1932–33, and from three equal adjoining untreated areas were weighed. The results, expressed in terms of pounds per 1,000 square feet, are recorded in Table 6.

TABLE 6.—*Aftereffect on Kentucky bluegrass of lead arsenate treatments for crabgrass.*

Pounds of grass, green weight, per 1,000 square feet								Percentage of normal growth
Oct. 31, 1932		Dec. 27, 1932		Feb. 15, 1933		Av. three dates		
Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	
				1934				
110	160	78	107	64	95	84	121	69
				1935				
322	393	198	247	168	216	229	285	80

From the yields it may be noted that the growth, on the average, amounted on the treated areas to 69 and 80% of that on the untreated areas in 1934 and 1935, respectively. These figures are subject to some error due to the presence of more crabgrass on the untreated than on the treated areas. This discrepancy, however, was not great, especially in 1934, for in that year the growth of crabgrass was sparse on account of drouth.

In 1935 the details of harvesting were so modified as to reveal the effect of the different rates of application individually. The weights are given in Table 7.

TABLE 7.—*Aftereffect on Kentucky bluegrass of lead arsenate applied at different rates.*

Pounds of lead arsenate per 1,000 sq. ft.	Pounds of grass, green weight, per 1,000 sq. ft.								Per cent of normal growth
	Oct. 31, 1932		Dec. 27, 1932		Feb. 15, 1933		Av. three dates		
	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	
10	355	384	244	282	190	210	263	292	90.1
15	327	434	208	248	175	214	237	299	79.3
20	321	421	189	243	155	213	222	292	76.0
25	301	399	192	252	149	217	214	289	74 0
30	329	364	199	239	170	225	233	276	84.4
35	332	404	178	220	164	217	225	280	80.4
40	292	347	177	242	174	213	214	267	80.1

The yields show that the lead arsenate reduced the growth in every one of the seven triplicate applications, 21 comparisons altogether. On the average, the plats which received the least lead arsenate made 90.1% of normal growth. On all the others the reduction was greater. Contrary to expectations, however, it did not decrease consistently as the rate of application of lead arsenate increased.

RECOVERY FROM AFTEREFFECT

FERTILIZATION

To determine if the recovery of grass injured by lead arsenate can be hastened through the use of fertilizer, one-half of each of the plats arsenated in 1932–33 was top-dressed with fertilizer. Poultry peat[3], Nitrophoska, and a 10 6-4 were used on the October, December, and February groups, respectively. The poultry peat was supplied at the rate of 200 pounds per 1,000 square feet (5 pounds nitrogen); the Nitrophoska (15–30–15) and the 10–6–4, each at the rate of 10 pounds per 1,000 square feet. One-half of each of the unarsenated or "check" plats were also fertilized with the same kinds and quantities of materials as were used on the arsenated areas. The top-dressings were made October 30, 1933, and April 23, 1935. During the season of 1934 the grass was cut and weighed in four parts as follows: (1) No treatment, (2) lead arsenate alone, (3) lead arsenate plus fertilizer, and (4) fertilizer alone. The results, expressed in pounds per 1,000 square feet green weight, are shown graphically in Fig. 2. The graphs show clearly that all the fertilizers revived the growth of grass to a point as good or better than that on the untreated area. Poultry peat

[3]A mixture resulting from the use of peat as litter in poultry houses, later dried and pulverized.

was the most effective, probably because it carried more nitrogen than did either of the other two fertilizers. Moreover, it was the only one of the three which restored the grass to its normal shade of green. The graphs show also that lead arsenate reduced the growth on the fertilized as well as on the unfertilized area.

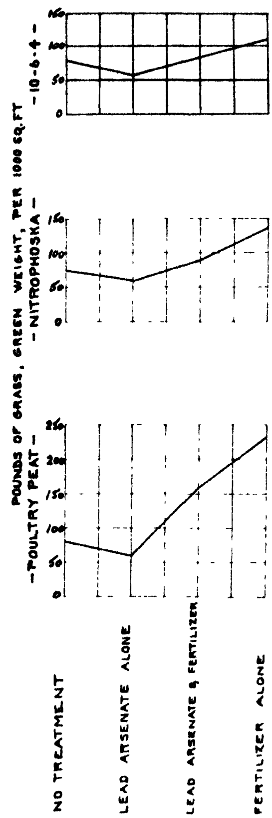

FIG. 2.—Effect of lead arsenate on the growth of grass.

LIMESTONE

On one area of the Station campus treated with lead arsenate October 31, 1932, and top-dressed with limestone and superphosphate October 30, 1933, the chlorosis of the grass was less marked than on an adjoining arsenated but unfertilized and unlimed area. In this connection it should perhaps be added that on a Wooster lawn treated with arsenate January 7, 1935, the degree of control obtained was somewhat less than that on the Station campus. This city lawn adjoined an oiled limestone street. The reaction of the soil was pH 6.7; whereas that of the Station campus where good control was obtained was pH 5.8. Possibly, the effectiveness of lead arsenate as an agent for the control of crabgrass is related to the limestone content of the soil.

DISTRIBUTION OF ARSENIC IN SOIL

In view of the injury to the grass an attempt was made to ascertain the distribution of the arsenic through the soil. Accordingly, in 1935, soil samples were taken in 1-inch horizons to a depth of 10 inches on the plats treated in 1930, 1931, 1932, 1933, and 1934. In three of the years, 1931, 1932, and 1933, samples were taken from plats to which lead arsenate had been applied at three rates, *viz.*, 10, 20, and 40 pounds, per 1,000 square feet, and in the others at one rate only. The rate or rates of application in each of the 5 years and the total arsenic found in each horizon expressed in terms of elemental arsenic per 1,000 square feet, are shown in Table 8.

If it is assumed that all the arsenic found came from that added as lead arsenate, then it can be seen from Table 8 that a part of the arsenic had penetrated the soil and that the larger the quantity applied, the greater the depth to which it had reached. In one case, 7.8 pounds of elemental arsenic applied in 1933–34 had penetrated at least 10 inches. The total amount found showed that some loss had occurred from each application. The heavier the application, the greater was the loss. Furthermore, from comparable plats it may be seen that the loss increased in general as the period of contact was extended. In this comparison the 1935 application was not included

TABLE 8.—*Pounds of elemental arsenic per 1,000 square feet recovered in 1935.*

Soil horizon, inches	Pounds of elemental arsenic per 1,000 square feet originally applied										
	1930 (campus)	1931–1932 (Martin yard)			1932–1933 (campus)			1933–1934 (campus)			1935 (watering plat)
	6.82	1.95	3.90	7.80	1.95	3.90	7.80	1.95	3.90	7.80	3.90
1	2.14	0.39	1.15	2.12	0.50	1.52	3.00	1.26	2.03	2.27	1.66
2	1.29	0.18	0.68	1.42	0.11	0.20	1.19	0.31	0.56	1.06	0.33
3	0.53	0.08	0.38	0.95	0.04	0.25	0.46	0.06	0.32	0.86	0.30
4	0.27	—	0.19	0.45	—	0.20	0.18	0.03	0.24	0.44	0.14
5	0.19	—	0.04	0.16	—	0.19	0.10	—	0.22	0.43	0.17
6	0.11	—	—	0.04	—	0.12	0.06	—	0.17	0.34	0.25
7	0.03	—	—	0.01	—	0.12	0.03	—	0.07	0.23	0.04
8	—	—	—	—	—	0.06	—	—	—	0.16	0.03
9	—	—	—	—	—	0.02	—	—	—	0.14	—
10	—	—	—	—	—	—	—	—	—	0.03	—
Total	4.56	0.65	2.44	5.15	0.65	2.68	5.02	1.66	3.61	5.96	2.92
Recovered, %	66.8	33.3	62.6	66.0	33.3	68.7	64.3	85.1	92.6	76.4	74.9
Lost, %	33.2	66.7	37.4	34.0	66.7	31.3	35.7	14.9	7.4	23.6	25.1

because it was not comparable on account of artificial watering. The percentage of loss from all applications, including the different rates, is shown at the bottom of Table 8.

On the soil samples taken from the single application made in 1930 and 1935 and on the ones representing the heaviest rate, 7.8 pounds per 1,000 square feet in 1931, 1932, and 1933, the water-soluble arsenic was determined. The results expressed in pounds of elemental arsenic per 1,000 square feet for each of the 10 horizons and for the 5 years are shown in Table 9. In no case was soluble arsenic found below the fourth inch.

The situation with reference to soluble arsenic in the upper 2 inches correlates closely with the appearance of the turf. The chlorosis of the grass which formerly was apparent on the plats treated in 1930 and 1931 has practically disappeared. On the plats treated in 1932 and 1933, chlorosis is still (1937) plainly visible. On the plat treated in 1935 the discoloration has never been very perceptible, probably because of the lighter application and in part perhaps because of the leaching from the artificial watering.

SUMMARY

1. Lead arsenate as an agent for the control of crabgrass proved to be effective in each of the 6 years it was used.

2. Applications made in October, December, February, and April were effective. Applications made in June were not effective the first

TABLE 9.—*Pounds of water-soluble elemental arsenic per 1,000 square feet found at different levels.*

Soil horizon, inches	1930 (campus)	1931–32 (Martin yard)	1932–33 (campus)	1933–34 (campus)	1935 (watering plat)
1	—	—	0.31	0.15	—
2	—	—	0.07	0.11	0.18
3	0.06	0.28	0.40	0.35	0.22
4	0.07	0.08	—	0.21	0.14
5	—	—	—	—	—
6	—	—	—	—	—
7	—	—	—	—	—
8	—	—	—	—	—
9	—	—	—	—	—
10	—	—	—	—	—
Total. . .	0.13	0.36	0.78	0.82	0.54

year but were in subsequent years. The crabgrass seedlings were in evidence at the time of the June application.

3. The rate of application ranged from 2.5 to 40 pounds per 1,000 square feet. From 20 to 25 pounds per 1,000 square feet usually gave almost complete control. Heavier rates increased the effectiveness little, if any. Lighter rates were noticeably less effective.

4. The lead arsenate was equally effective whether applied (1) in mixture with soil, (2) as dust, or (3) as spray. The proportion of soil to arsenate did not affect materially the degree of control.

5. Calcium arsenate, pound for pound, was more effective than lead arsenate; 15 pounds per 1,000 square feet of the former giving practically as good results as 25 pounds of the latter. Calcium arsenate, however, injured and in fact killed some of the grass when used in quantities heavier than 15 pounds per 1,000 square feet. The action of manganese arsenate was more nearly like that of calcium than of lead arsenate. The use of arsenic pentoxide proved impractical for even in moderate quantities it killed the desirable grasses.

6. Lead arsenate injured the grass somewhat. The brownish appearance did not appear until a year or more after application. The quantity of growth was reduced 31 and 20% the second and third years, respectively, after treatment.

7. The bad aftereffect from the use of lead arsenate was overcome by the liberal use of fertilizers rich in nitrogen. The addition of limestone also improved the appearance of the grass.

8. Analyses of the soil showed that with the heaviest rate of application the arsenic had penetrated to a depth of at least 10 inches. Even with the heaviest rates of application no water-soluble arsenic was found at a greater depth than 4 inches.

FERTILIZING CONSTITUENTS OF COTTON BURS OR COTTON BUR ASHES AND THEIR EFFECT ON CROP YIELDS[1]

Horace J. Harper, Harley A. Daniel, and Garth W. Volk[2]

CONSIDERABLE data (8, 10, 12, 13)[3] have been published on the chemical composition of cotton plants, but little information is available concerning the fertilizing value of the burs and their ashes. Fraps (6) states that where yields of 1,000 to 1,200 pounds of seed cotton per acre are produced, the amount of burs for each 300 pounds of seed is about 160 pounds. McBryde (9) found that 14.21% of a mature dry cotton plant is burs. More than 50% of the cotton in western Oklahoma is harvested by snapping, consequently large quantities of burs accumulate at the gins during the ginning operations. The disposal of this material depends upon local conditions and many inquiries are received annually concerning the utilization of the ash. If the burs are not burned, they are usually scattered on fields near the gins and the rate of application in tons per acre is usually high.

EXPERIMENTAL PROCEDURE

The effect on the yield of seed cotton of applying cotton burs and their ashes to Kirkland soil has been studied since 1926 at Oklahoma Agricultural Experiment Station. This soil contains about 2,000 pounds of total nitrogen per acre in the surface 6⅔ inches which is higher than the average nitrogen content of the upland soils where cotton is usually planted. The burs were applied at intervals of 3 years on different plats at rates of 3 and 6 tons per acre, respectively, except during the first season, when the rate was 1 and 3 tons per acre. On one series of plats the treatments were applied before the land was plowed. In order to study the effect of different methods of application, burs were scattered over the surface of plowed land on adjacent plats and disked into the soil. Two plats were also treated in a similar manner with ashes equivalent to 3 and 6 tons of burs per acre.

Cotton burs were collected during the fall of 1937 from several counties in Oklahoma, and all seed, lint, and trash were removed. The samples were finely ground in a Wiley mill, oven dried at 105° C, and analyzed for total ash, nitrogen, phosphorus, and calcium by methods recommended by the Association of Official Agricultural Chemists. Magnesium was determined by a method recommended by Dean and Truog (3) and potassium by the sodium cobaltinitrite method (11).

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[1]Contribution from the Department of Agronomy, Oklahoma Agricultural Experimental Station, Stillwater, Okla. Received for publication July 1, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 831.

RESULTS OF EXPERIMENTS

EFFECT OF COTTON BURS AND THEIR ASHES ON YIELD OF SEED COTTON

The fertilizing value of cotton burs and their ashes on the yield of seed cotton was studied and the results are recorded in Table 1. Although the seasons from 1934 to 1937 were very unfavorable for the production of cotton, the average increases in yield are significant. Ashes from an equivalent amount of burs only produced about one-half as great an increase in yield as the burs. Crop residues returned to the soil provide more favorable conditions for absorption and retention of water and have a desirable effect on tilth. In addition, the nitrogen they contain is available for plant use after decomposition has occurred. The combined effect of these factors should be recognized in order to explain the increased yield received from the burs. Three tons of burs applied at intervals of 3 years, either plowed or disked into the soil, give as good returns as 6 tons on adjacent plats treated in a similar manner. The average increase in yield was 189 pounds of seed cotton per acre when the light application was plowed under and 166 pounds when disked into the soil. The highest average gain from the heaviest treatment was 170 pounds per acre. These tabulations show that the light rate of fertilization was slightly more effective than the heavy treatment during this period. Cotton burs reduce the available nitrogen content of soil for a considerable period after they are applied (5); consequently, crops requiring a large amount of available nitrogen may suffer if planted before these residues have decayed sufficiently to narrow the carbon-nitrogen ratio to a point where nitrates can accumulate in the soil.

Results from a heavy application of ashes are slightly less than those obtained from the lighter treatment. The average increase in yield from the ashes from 3 tons of burs applied at intervals of 3 years was 75 pounds of seed cotton per acre and that from 6 tons treated in a similar manner, 61 pounds. Since the soil on the Oklahoma Agricultural Experiment Station farm does not give much response from potash fertilization, the results of this experiment might be considerably different if conducted on a soil deficient in available potassium.

COMPOSITION OF COTTON BURS AND THEIR ASHES

In order to secure information on the chemical composition of cotton burs and their ashes, 33 samples from 22 counties in Oklahoma were analyzed and the results recorded in Table 2. Some burs contained twice as much calcium, nitrogen, and total ash, and three times as much phosphorus and potash as other samples, while magnesium varied less than any other element. The average potassium content was higher than that obtained by other investigators (4, 5). The wide variation in the composition of this material is probably due to several factors, such as difference in soil, climatic conditions, and variety. The soils in the different areas from which these burs were obtained vary greatly in ferrility (1, 7), and this condition may be responsible for a part of the difference occurring in the composition

TABLE 1.—*The effect of cotton burs and their ashes on the yield of seed cotton at Stillwater, Oklahoma.*

Plat No.	Treatment and rate of application per acre*	Pounds of seed cotton per acre											Average, lbs. per acre	
		1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	Yield	Increase in yield
1 and 5	None	1,450	1,520	940	190	590	1,015	910	242	127	10	290	662	—
2	Ashes from 3 tons of burs†	1,820	1,730	1,100	180	660	1,080	780	272	174	30	284	737	75
3	3 tons of burs†	1,950	2,130	1,050	240	660	1,320	1,000	296	196	28	244	828	166
4	3 tons of burs‡	2,000	2,080	1,040	250	780	1,270	1,100	324	186	31	300	851	189
6 and 10	None	1,510	1,645	940	210	710	790	980	238	165	19	245	677	—
7	Ashes from 6 tons of burs†	1,670	1,700	1,180	200	800	880	920	264	200	32	268	738	61
8	6 tons of burs†	1,925	2,300	1,070	260	740	1,160	1,080	260	200	46	274	847	170
9	6 tons of burs‡	1,860	1,620	1,115	260	800	1,220	1,100	336	250	44	388	817	140

*Thirteen tons of cotton burs or the equivalent amount of ashes per acre have been applied to plats 2, 3, and 4, and 27 tons to plats 7, 8, and 9. One ton was added to the former and 3 tons to the latter in 1926, while the treatment was 3 and 6 tons, respectively, during the fall of the following seasons: 1927, 1930, 1933, and 1936.

†Applied on plowed land and disked into the soil.

‡Plowed into the soil.

TABLE 2.—*The composition of cotton burs and their ashes.*

Sample No.	County	Percentage of ash and nutrients in burs						Percentage of elements in ash			
		Ash	N	P	Ca	K	Mg	P	Ca	K	Mg
1	Beckham	11.02	0.76	0.07	0.69	5.74	0.22	0.60	6.26	52.08	2.00
2	Caddo	9.75	0.77	0.07	0.66	4.97	0.26	0.70	6.80	50.93	2.66
3	Carter	7.22	0.99	0.08	0.65	3.16	0.28	1.05	9.05	43.78	3.93
4	Choctaw	5.93	0.72	0.13	0.51	2.86	0.22	2.24	8.58	48.16	3.71
5	Cleveland	10.75	0.93	0.09	0.83	4.12	0.34	0.83	7.70	38.30	3.14
6	Coal	7.71	1.06	0.07	0.54	3.75	0.28	0.87	7.01	48.72	3.60
7	Coal	8.02	1.11	0.17	0.64	3.66	0.29	2.15	8.01	45.68	3.60
8	Cotton	10.74	1.07	0.08	1.02	4.46	0.34	0.79	9.53	41.52	3.15
9	Greer	10.52	0.87	0.07	0.79	5.02	0.26	2.16	7.53	47.79	2.51
10	Harmon	11.55	1.17	0.15	0.80	5.71	0.28	1.27	6.91	49.46	2.44
11	Hughes	5.93	1.05	0.08	0.48	2.61	0.22	1.38	8 15	44.00	3.68
12	Jackson	8.14	0.95	0.08	0.80	3.14	0.24	1.00	9.84	38.75	2.78
13	Jefferson	7.95	1.00	0.08	0.71	2.38	0.25	0.96	8.97	29.85	3.16
14	Jefferson	7.00	1.05	0.07	0.68	2.28	0.23	1.05	9.75	32.50	3.33
15	Kingfisher	8.58	1.40	0.12	0.81	3.42	0.28	1 43	9.43	39.81	3.31
16	Kiowa	10.67	0.97	0.11	0.83	5.07	0.30	1.04	8.07	47.49	2.85
17	Lincoln	10.27	0 78	0.09	0.61	3.79	0.28	0.91	5.95	37.53	2.77
18	McIntosh	6.70	1.33	0.21	0.61	2.25	0.29	1.43	9.07	33.63	4.31
19	Muskogee	6.12	1.31	0.12	0.52	2.07	0.23	2.04	8.42	33.83	3.76
20	Payne	13.09	1.27	0.15	0.86	6.25	0.27	1.18	6.56	47.77	2.06
21	Payne	9.92	1.07	0.08	0.67	5.12	0.23	0.77	6.71	51.60	2.30
22	Payne	9.98	1.25	0.10	0.70	2.65	0.21	1 00	6.99	26.50	2.06
23	Payne	12.03	1.30	0.09	0.72	2.31	0.23	0.85	6.58	19.20	2.13
24	Tillman	9.35	1.01	0.11	0 74	3.51	0.28	1.22	7.86	37.52	2.96
25	Tulsa	4.98	1.25	0.11	0.44	1.88	0.19	2.15	8.86	37.80	3.73
26	Wagoner	11.16	1.25	0.11	0.55	1.60	0.20	0.99	4.90	16.00	1.82
27	Wagoner	7.07	1.24	0.08	0.50	1.42	0.20	1.18	7.06	20.10	2.89
28	Wagoner	8.07	1.16	0.10	0.51	1 67	0.22	1.23	6.40	20.70	2.64
29	Wagoner	8.43	1.13	0.10	0.59	1.72	0 21	1.10	7.00	20.30	2.57
30	Washita	9.12	1.38	0.12	0.75	4.19	0.28	1.32	8.22	45.92	3.06
31	———	9.97	1.01	0.09	0.67	4.90	0 30	0.88	6.72	49 15	3.05
32	———	10.36	0.88	0.08	0.70	4.18	0 28	0.79	6 79	40.49	2.70
	Average	8.73	1.04	0.10	0.65	3.39	0.25	1.17	7.44	37.48	2.87
	Average as oxides	——	——	0.23	0.91	4.08	0.41	2.68	10.41	45.15	4.76

of the samples. Since drought decreases the phosphorus content of alfalfa and prairie hay and since calcium seems to increase under such conditions (2), it is quite probable that cotton burs produced on the same field during different seasons or during the same season may vary in composition.

The amount of each element in the cotton bur ashes was calculated from the percentage of total ash in the dry material. From a fertilizer standpoint, the most important constituent in the ash is potassium. The percentage of this element ranged from 16.00 to 52.08 in various samples. The average percentage was 37.48, which is almost as high as the potassium content of commercial grades of high potash fertilizers. In addition to this very valuable ingredient, there were considerable quantities of other elements that are frequently deficient in soils. The various elements in the ash were calculated as oxides, with average percentages as follows: Phosphoric acid, 2.68; calcium oxide, 10.41; potassium oxide, 45.15; and magnesium oxide, 4.76; a total of 63.00% of important fertilizing constituents.

Although soils in western Oklahoma do not usually respond to applications of phosphate, potash, or lime, fertilization with small quantities of cotton burs may be beneficial on many farms because the nitrogen and organic matter in most cultivated soils are rapidly disappearing as a result of tillage, cropping, and erosion. Farmers who haul snapped cotton to a gin and fail to return the burs are losing approximately 21 pounds of nitrogen for each ton of burs removed from their land. This amount of nitrogen is greater than the nitrogen occurring in one-half bale of seed cotton.

SUMMARY

The effect of applying cotton burs and their ashes to Kirkland soil on the yield of seed cotton has been studied at Oklahoma Agricultural Experiment Station since 1926. Three tons of burs applied at intervals of 3 years, either plowed or disked into the soil, give as good returns as 6 tons on adjacent plats treated in a similar manner. The average increase was 189 pounds per acre when the lightest application was plowed under and 166 pounds when disked into the soil. The highest average gain from the heaviest treatment was 170 pounds of seed cotton per acre. Ashes from equivalent amounts of burs only produced about one-half as great an increase in yield as the burs.

Cotton burs were collected from 22 counties in Oklahoma and analyzed for their fertilizing constituents. These samples contained an average of 8.73% ash, 1.04% nitrogen, 0.10% phosphorus, 0.65% calcium, 3.39% potassium, and 0.25% magnesium, calculated on a moisture-free basis. The nutrient content of cotton bur ashes was calculated, and the average quantity of different oxides was found to be as follows: Phosphoric acid (P_2O_5), 2.68%; calcium oxide, 10.41%; potassium oxide, 45.15%; and magnesium oxide, 4.76%.

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EFFECT OF CERTAIN CROPS AND SOIL TREATMENTS ON SOIL AGGREGATION AND THE DISTRIBUTION OF ORGANIC CARBON IN RELATION TO AGGREGATE SIZE[1]

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CROPS differ with respect to their influence on the physical properties of the soil. Certain crops appear to leave the soil upon their removal in a mellow or friable condition, while others apparently exert little effect and still others cause the soil to become "hard." Most of this knowledge is based on purely qualitative observations in the field, though quantitative measures in the form of plow draft tests, ease of penetration tests, and, more recently, aggregate analyses, have been used. Until recent years no methods were available by which the degree of aggregation of soils could be satisfactorily measured. Several methods have now been proposed which offer promise of yielding very valuable results. Among these may be mentioned the elutriation method proposed by Baver and Rhoades (3),[3] the wet sieve method described by Yoder (11), the sedimentation tube method of Cole and Edlefsen (6), and methods involving the use of the hydrometer reported by Bouyoucos (5) and Gerdel (8).

On purely theoretical grounds the writers believe that the sedimentation tube method of Cole and Edlefsen should be the most desirable type of procedure in aggregate analysis because in this method mechanical abrasion is reduced to a practical minimum. The objections based on particle density, particle shape, and particle size raised by Yoder against the elutriation method, however, apply to the Cole and Edlefsen procedure as well. These objections, the writers believe, are more than offset by the reduction in mechanical abrasion of the sedimentation tube method as compared to the wet sieve procedure.

The Cole and Edlefsen soil tube was used in the work reported here. The procedure recommended by them was found to be satisfactory and with strict adherence to its details reproducible results could be obtained. Appreciable variations in time of slaking the soil, method of mixing the sample, or draining the tube always resulted in measurable variations in the data.

EFFECT OF SOME CROPS AND SOIL TREATMENTS ON SOIL AGGREGATION

FIELD STUDIES

Samples taken from field plats supporting various crops were studied and a few samples from an experiment involving periods of fallow of various lengths were utilized. A majority of the samples

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[3]Figures in parenthesis refer to "Literature Cited", p. 842.

involved in the comparison of the effects of various crops were taken from adjacent long, narrow plats, 13½ feet by 161⅓ feet. Plats of such shape are desirable in this type of study since inherent differences in soil morphology are encountered if the samples for comparison are not drawn within comparatively narrow limits. Inherent differences in aggregation are oftimes greater than those produced by different vegetative cover. Some of the samples used in this study, however, were taken from adjacent 1/10 acre plats, 27 feet by 161⅓ feet.

The samples were removed from the plats with a spade and care was exercised to take that portion of the soil removed at each spadeful which was apparently not compacted in the removal. Six such samples, taken to a depth of 6 inches, were mixed together on a piece of canvas and a composite sample removed for analysis. This composite sample was carefully screened through a wire screen with ½-inch mesh, mixed thoroughly and a quantity sufficient to supply approximately 54 grams of oven-dry soil was removed for analysis.

The results of the analyses of the field samples are listed in Table 1. The samples are grouped in the manner in which comparisons should be made.

It will be noted from the data in Table 1 that duplicate comparisons were obtained in most cases. In general these show very good agreement. In Fig. 1 the data from one pair of plats in each of the following comparisons are shown graphically; corn and kafir, oats after corn and oats after kafir, 1 year of fallow and 2 years of fallow.

The slaked and mixed soil in the tube was allowed a 30 seconds sedimentation period, with the tube in a vertical position. After this period the tube was turned to an exactly horizontal position and the suspended soil allowed to settle on the segments of the inner tube. In Table 1 and Fig. 1 are shown only the summation percentages for the top 10 segments, referring to the tube in a vertical position. The lower five segments are disregarded because of the influence of the increased viscosity, or the "piling-up" effect, resulting from the concentration of soil particles at these lower depths during the sedimentation period. It should be borne in mind in interpreting the data of the table or graph that the more aggregated the soil the lower are the summation percentages for the upper 10 segments, and *vice versa*.

There are several points of interest in these data. It is commonly believed that a sorghum crop, for some reason possibly never adequately explained, produces an unfavorable after-effect upon the physical condition of the soil. These data indicate that at the time the crops matured there was practically no difference in the aggregation of the soil under corn and that under sorghum. Later, however, when the same plats were sampled under oats stubble, there was a distinctly greater degree of aggregation in the soil of the plat whose previous crop had been corn than in the one where sorghum preceded the oats. This occurrence makes it appear that the unfavorable after-effect of sorghums on the physical condition of the soil, if any, originates during the decomposition of the sorghum residues. On these plats all of the corn and kafir stover as well as the stubble and roots are returned to the land. Therefore if a dispersing action is created

TABLE 1.—*Aggregation of soil as affected by various crops under field conditions.*

Crop	Percentage of the total sample having particles with mean settling velocities equal to or less than the indicated amount in centimeters per second									
	0.085	0.254	0.423	0.592	0.762	0.931	1.100	1.270	1.439	1.608
Corn (a)*	3.40	6.80	10.44	14.36	18.44	22.75	27.35	32.16	37.14	42.46
Kafir (a)	3.39	6.88	10.74	14.64	18.78	23.09	27.81	32.71	37.79	43.02
Corn (b)	2.96	6.13	9.65	13.36	17.31	21.55	26.09	30.85	35.83	40.93
Kafir (b)	2.87	5.92	9.28	12.95	16.84	20.97	25.37	30.00	34.76	39.77
Oats after corn (a)	2.72	6.31	9.86	13.65	17.66	21.89	26.27	30.77	35.53	40.31
Oats after kafir (a)	4.12	8.34	12.69	17.24	22.00	27.03	32.10	37.25	42.46	47.91
Oats after corn (b)	3.72	7.73	11.88	16.33	20.78	25.58	30.71	35.95	41.23	46.77
Oats after kafir (b)	4.69	9.38	14.36	19.41	24.63	30.00	35.51	41.09	46.75	52.53
2 yrs. alfalfa (a)	3.72	7.15	10.92	14.92	19.09	23.50	28.05	32.88	37.87	42.97
2 yrs. sweet clover (a)	3.71	7.48	11.39	15.52	19.75	24.31	29.16	34.19	39.31	43.70
2 yrs. alfalfa (b)	3.03	6.17	9.55	13.14	16.93	21.12	25.59	30.34	35.26	40.35
2 yrs. sweet clover (b)	2.92	6.22	9.71	13.39	17.21	21.35	25.76	30.32	35.05	39.91
Soybeans (a)	4.17	8.28	12.73	17.38	22.21	27.28	32.56	38.16	43.69	49.51
1 yr. sweet clover (a)	3.35	6.81	10.60	14.65	18.92	23.35	28.08	33.06	38.29	43.68
Soybeans (b)	3.74	7.55	11.67	15.95	20.43	25.25	30.39	35.53	40.79	46.17
1 yr. sweet clover (b)	3.48	7.02	10.92	15.00	19.30	23.77	28.53	33.46	38.51	43.73
Fallow 1 yr., alfalfa 2 yrs.	1.21	2.21	3.28	4.48	5.80	7.22	8.80	10.52	12.36	14.36
Fallow 2 yrs., alfalfa 1 yr	1.51	2.99	4.67	6.42	8.44	10.61	12.87	15.30	17.83	20.65
Fallow 1 yr., soybeans 2 yrs.	1.80	3.58	5.50	7.56	9.85	12.55	15.50	18.27	21.65	25.04
Fallow 2 yrs., soybeans 1 yr	2.40	4.47	7.45	10.20	13.30	16.67	20.38	23.75	27.88	32.10
Fallow 1 yr., corn 2 yrs.	1.85	3.42	5.12	7.15	9.12	11.43	13.78	16.32	18.95	21.87
Fallow 2 yrs., corn 1 yr	2.12	4.09	6.34	8.82	11.41	14.40	17.56	20.86	24.58	28.33

*Letters indicate duplicated treatment.

when the sorghum residues undergo decomposition such dispersion should be at its maximum under the conditions existing in this experiment. Breazeale (4) noted that the dispersing action occurred after the sorghum crop was removed and during the decay of its residues. His explanation of the cause is probably not valid for acid soils. Ayyar, Kasinath, and Balakrishnan (2) suggest that an increase in the active sodium of the soil following sorghum cropping may be a cause.

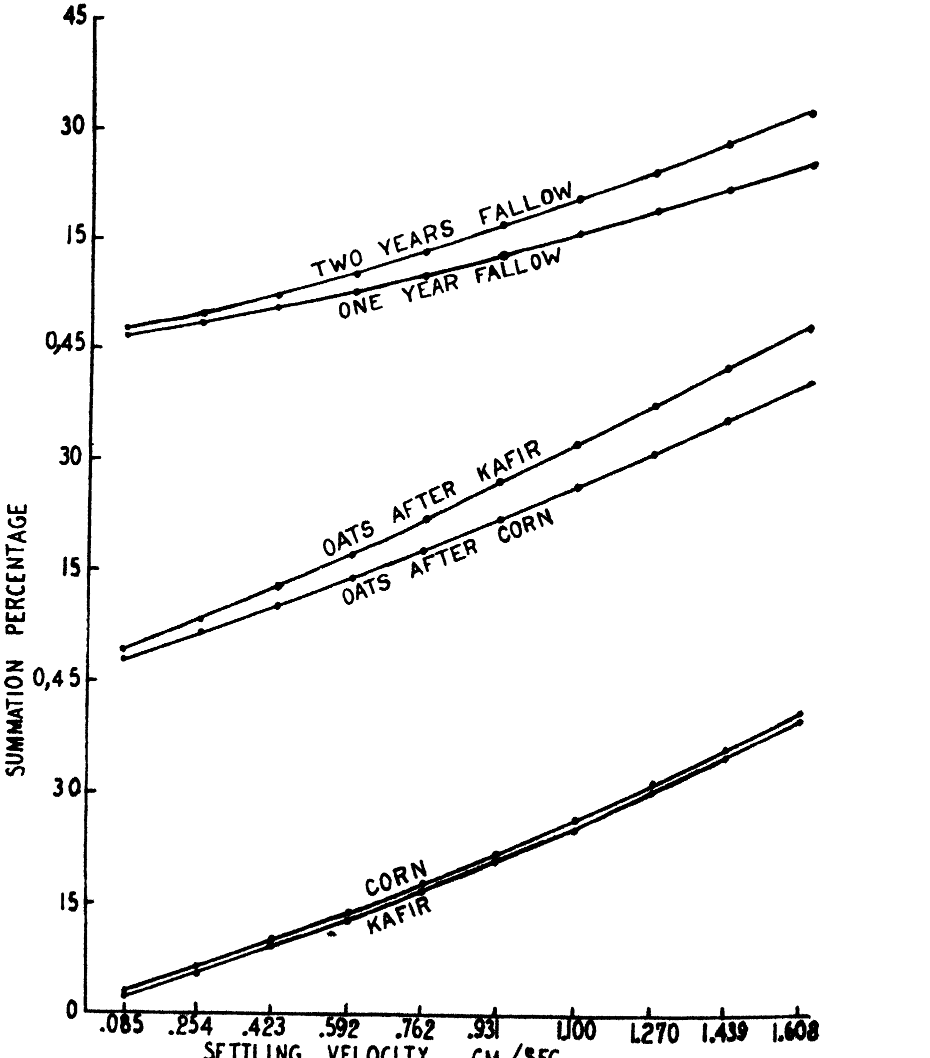

FIG. 1.—Curves showing the summation percentages of aggregates with settling velocities equal to, or less than, the indicated values, for three paired experiments.

A second point of interest is the similarity of the values for alfalfa and sweet clover. The latter, however, left the soil appreciably better aggregated after one summer's growth than did soybeans. A third point of interest is the difference in the degree of aggregation between soil fallowed for 1 year and cropped for 2 years, on the one hand, and soil fallowed for 2 years and cropped for 1 year on the other. Soil fallowed 2 years or more under the rainfall conditions existing at this station loses by leaching soluble salts produced in the surface soil and undergoes some eluviation. In such soil a thin, compact zone or layer develops a few inches below the surface. The effect is indicated in the aggregate analysis data for the plats fallowed for 2 years. The soil on which the fallow experiment is located is distinctly different from that on which the crops listed in the first part of the table were grown. The fallow soil, which has not been correlated recently, would probably be classified as a deep phase Derby silt loam. It is better aggregated than the Derby silt loam represented in the first part of the table.

GREENHOUSE STUDIES

It was desired to study the effect of several crops and of the use of lime upon soil uniformly prepared and cropped under controlled conditions in the greenhouse. Soil from an area in the fallow experiment mentioned above which had been fallowed for 3 years and which had developed a compact zone was used for the greenhouse study. The dispersing effect which it had undergone, it was believed, would make it a desirable soil for this experiment. It had a high organic matter content, however, and subsequent results made it appear that it was not a particularly good choice. The pH value of the soil was 5.7 and precipitated $CaCO_3$ was applied to certain jars at the rate of 2 tons per acre on a weight basis, the lime being mixed with the entire mass of soil.

The soil was removed with a shovel and brought to the greenhouse where it was screened through a ½-inch screen. It was then thoroughly mixed and weighed quantities placed in 2-gallon stone jars. The soil was treated or cropped as noted in the following table. Triplicate jars for each treatment or crop were provided. When the shortest season crops began to approach maturity the process of taking down the jars was started as rapidly as the samples could be analyzed One jar of each crop or treatment was taken down. When one of each of the triplicates had been analyzed a second series was likewise removed and finally the third. The average length of time each treatment or crop reacted upon the soil is therefore comparable to all others. When each jar was taken down the plants were removed, the soil put through a ½-inch screen, thoroughly mixed, and a portion removed for analysis. Good agreement between triplicates was obtained when strict adherence to procedures was practiced. The results obtained from the triplicate determinations in each case were averaged and the averages are shown in Table 2.

Some of the results obtained from this experiment were rather surprising. For example, the soil kept bare in the greenhouse (listed as fallow in the table) and in which was maintained a moisture con-

TABLE 2.—*Soil aggregation as affected by various crops under greenhouse conditions.*

Soil treatment or crop	Percentage of the total sample having mean settling velocities equal to or less than the indicated amount, in centimeters per second									
	0.085	0.254	0.423	0.592	0.762	0.931	1.100	1.270	1.439	1.680
Original soil	1.59	3.27	5.04	7.05	9.31	11.80	14.48	17.35	20.39	23.51
Fallow, not limed	1.28	2.60	4.04	5.60	7.41	9.28	11.31	13.81	15.78	18.29
Fallow, limed	1.31	2.63	4.09	5.67	7.49	9.40	11.43	13.61	15.92	18.34
Sweet clover, not limed	1.79	3.53	5.41	7.43	9.11	11.98	14.52	17.14	19.87	22.76
Sweet clover, limed	1.26	2.45	3.83	5.35	7.06	8.89	10.85	12.93	15.13	17.49
Red clover, not limed	1.81	3.60	5.55	7.68	9.99	12 53	15.12	28.03	21.01	24.28
Red clover, limed	1.46	2.97	4.60	6 40	8.45	10.68	13.13	15.75	18.54	21.48
Bluestem*	2.14	4.17	5.71	8.74	11.27	14.03	16.92	20.00	23.17	26.54
Bluegrass†	2.00	4.06	6.28	8.56	11.05	13 66	16.53	19.47	22.52	25.72
Buffalo grass‡	1.78	3.66	5.71	7.98	10.42	13.12	15.98	19.18	22.29	25.71
Wheat	1.63	3.27	4.76	7.05	9.22	11.61	14.18	16.97	19.87	22.96
Corn	1.87	3.60	5.42	7.41	9.62	12.14	14.50	17.22	20.06	23.03
Kafir	1.61	3.06	4.65	6.35	8.27	10.32	12.57	14.96	17.54	20.22
Soybeans	1.43	2.78	4.37	6.08	8.07	10.28	12.49	15.01	17.68	20.91

**Andropogon scoparius.*
†*Poa pratensis.*
‡*Buchloe dactyloides.*

dition similar to that of fallow in the field, showed a greater degree of aggregation than the original soil or the soil of any except one of the cropped jars. The limed and unlimed fallow soil showed almost identical results. The reason for the behavior of the uncropped soil is somewhat obscure. However, as explained before, the soil was high in its content of organic matter. The jars were not provided with drains and the temperature and moisture conditions were very favorable for biological activity. Hence any soluble salts released accumulated in the soil. Furthermore, downward movement of water was restricted. These facts may account for the high degree of aggregation of this soil. Conrad (7) has shown a relationship between nitrate accumulation and flocculation of soil colloids.

Grasses had surprisingly little effect on aggregation. The three types used produced very similar values and the soil from beneath the grasses was less aggregated than that from beneath any other crop or treatment. The bluestem grass and the buffalo grass, which were transplanted from the field, did not do particularly well in the greenhouse. The bluegrass, however, also transplanted, grew luxuriantly. It is probable the growth period was too short for the plants to exert a beneficial effect upon the physical condition of the soil. It may be, however, that grasses, after all, are not particularly effective in promoting soil aggregation, at least not over a short period of time.

Wheat and corn were indicated to have influenced the soil in a very similar manner. The soil under kafir was better aggregated than that under corn, while soybeans produced values similar to those for the sorghum crop.

Red clover and sweet clover in unlimed soil gave results similar to those for corn and wheat. When the soil was limed, however, and these crops grown, the degree of aggregation was appreciably increased despite the fact that there was no noticeable response of the plants to lime on this soil.

There have been some differences of opinion among soil scientists regarding the relationship of lime, or more specifically, calcium, to soil aggregation. It has long been believed that the use of lime on lime-deficient soils under field conditions promoted granulation in such soils. Very few data were ever presented to prove that such a process actually occurred. On the other hand, laboratory studies have indicated that H^+ saturated soils were as well or better aggregated than soils saturated with Ca^{++}. The results of the study presented in this paper may assist in harmonizing these views. It may be that the field observations and the laboratory results are both logical, but that it requires the combined action, or interaction, of lime and plant to produce improved soil aggregation. The problem requires further study.

DISTRIBUTION OF ORGANIC CARBON IN RELATION TO AGGREGATE SIZE

Numerous workers have reported results indicating an important rôle of organic matter in soil aggregation. Among recent papers may be mentioned those of Sideri (10) and Myers (9). While making the aggregate analyses reported in this paper, it was observed that the

least aggregated soil fractions were lighter in color than the better aggregated soil. It was believed the lighter color was attributable to a lower content of organic matter. Accordingly, samples were collected for organic carbon determinations. Samples from two segments from near that end of the tube which was uppermost during the sedimentation period were selected to represent the least aggregated soil. These segments were designated Nos. 3 and 4. Segment No. 1 at the top was not used since light, undecomposed organic matter always floated to the surface and contaminated the sample on this segment. Segment No. 2 was tried, but it appeared that some such contamination occurred there also. Samples from segments 8, 9, and 10 were utilized to represent slightly better aggregated soil and samples from the lowest segments, 12, 13, 14 and 15, were used to represent soil best aggregated. Such studies were made with from 6 to 8 field soil samples and 12 to 13 samples from the greenhouse experiment. Since the results are very similar only the data from the field samples are presented. Organic carbon was determined by the Schollenberger method as outlined by Allison (1). The results are listed in Table 3.

TABLE 3.—*Organic carbon of differently aggregated portions of the soil.*

Field experiment sample description	Percentage of organic carbon in the soil on tube sections indicated									
	Top			Middle			Bottom			
	2	3	4	8	9	10	12	13	14	15
Kafir (a)*.	1.59	1.35	1.45	1.38	1.51	1.39	1.54	1.60	1.65	—
Corn (a)	1.45	1.34	1.29	1.47	1.58	1.46	1.51	1.58	1.66	—
Kafir (b). ..	—	1.62	1.59	1.66	1.63	1.69	—	1.73	1.89	1.82
Corn (b) . .	—	1.64	1.68	1.71	1.74	1.73	—	1.82	1.85	1.87
Oats after kafir (a)	—	1.46	1.56	1.62	1.52	1.64	—	1.74	1.80	1.84
Oats after corn (a)	—	1.56	1.51	1.55	1.55	1.56	—	1.65	1.73	1.74
Oats after kafir (b)	—	1.32	1.32	1.40	1.32	1.41	—	1.47	1.32	1.43
Oats after corn (b)	—	1.37	1.41	1.47	1.44	1.47	—	1.45	1.47	1.51

*Letters in parentheses indicate duplicated treatments.

The data indicate differences in organic carbon content which are rather consistent. In order, however, to obtain a better measure of the importance of the differences, comparisons were made by Student's method (Love's tables) of pairs of aggregate groups from the data for the field samples and also for the greenhouse samples. The comparisons and the odds supporting the differences are shown in Table 4.

The differences of organic carbon content between the less aggregated portions of the soil and the more aggregated portions are significant. Out of 16 mean differences obtained from paired groups made up of from 6 to 13 comparisons, 14 are supported by significant odds. No explanation can be offered for the result of the last comparison listed in the table which shows a negative mean difference, that is, the aggregates on segment 9 showed slightly more organic carbon on the average than those on segment 15. This result is at variance with that obtained from the field data.

TABLE 4.—*Comparison of organic carbon of soil samples from various segments of the soil tube and odds for significance of the differences.*

Comparison, tube segments	Mean difference, %	Standard deviation	Z value	n	Odds
		Field Experiment			
3 with 8	.075	.055	1.36	8	225 to 1
3 with 9	.080	.081	0.99	8	56 to 1
4 with 9	.060	.098	0.61	8	12 to 1
3 with 13	.170	.077	2.19	8	3100 to 1
4 with 14	.195	.120	1.62	8	550 to 1
4 with 15	.190	.072	2.64	6	985 to 1
9 with 13	.090	.071	1.27	8	164 to 1
10 with 14	.130	.116	1.12	8	94 to 1
10 with 15	.120	.073	1.63	6	132 to 1
9 with 15	.170	.088	1.93	6	258 to 1
		Greenhouse Experiment			
3 with 9	.297	.122	2.43	12	>10,000 to 1
4 with 10	.170	.152	1.12	12	550 to 1
3 with 14	.370	.366	1.01	12	310 to 1
4 with 15	.210	.174	1.21	12	950 to 1
8 with 14	.135	.125	1.08	13	725 to 1
9 with 15	-.03	.171	-.175	13	0 to 1

ULTIMATE MECHANICAL COMPOSITION OF SOME OF THE AGGREGATE SEPARATES

The presence of more organic carbon in the more aggregated portions of the soil as demonstrated by these data lends weight to the assignment of an important rôle to organic matter in the process of soil aggregation. It seems possible, too, that the differences in carbon content may represent the more active portion of the organic matter and probably that portion which is most effective in the binding of the mineral particles into aggregates.

It was considered possible that the differences in organic matter content of the various aggregate groups might not be particularly significant if ultimate particle size also differed appreciably in these groups. Since the quantities of soil recoverable from the upper segments of the tube were small, numerous samples from various segments were composited, thoroughly mixed, and a mechanical analysis made. Organic matter was not removed, but the soil was dispersed and the determinations were made by the Bouyoucos hydrometer method. The distribution of ultimate particles as thus determined is indicated in Table 5.

The results listed in Table 5 indicate little or no tendency toward ultimate particle separation in the aggregate analysis method used. The slightly higher value for total sands in segments 1 to 5 may be accounted for, at least in part, by the undecomposed organic matter in these segments which, in the mechanical analysis floated to the surface of the suspension and consequently did not affect the hydrometer. It is believed, therefore, that the aggregate analysis data presented offer a true picture of the degree of aggregation of the soil.

TABLE 5.—*Ultimate particle distribution in the aggregate separates.*

Tube segments	Total sands %	Silt %	Clay %
1–5 (upper)	24	54	22
6–9 (middle)	20	56	24
10–12 (lower middle)	19	60	21
13	23	56	21
14	21	56	23
15	21	54	25

Also the distribution of organic carbon among the various separates takes on added significance when it is revealed that ultimate particle size in these aggregates is similar.

SUMMARY

Studies of the effect of several crops and certain soil treatments on the degree of aggregation of soils in the field and in the greenhouse are presented. The organic carbon contents of various size groups of soil aggregates obtained from a single soil sample were determined.

Samples taken from the soil under growing corn and kafir in field and greenhouse showed as good aggregation under the sorghum crop as under corn. When oats succeeded these two crops in the field, however, soil samples removed from the oats stubble revealed a greater degree of dispersion where oats followed sorghum than where corn was the preceding crop. Sweet clover left the soil better aggregated after 1 year's growth than soybeans, while alfalfa and sweet clover gave similar results. Soil fallowed for 2 years in the field was less aggregated than soil fallowed for 1 year.

Limed soil supporting sweet clover and red clover in a greenhouse experiment was more highly aggregated than similar soil unlimed but supporting these crops. Unlimed and unleached fallow soil in the greenhouse was as well aggregated as limed fallow soil. It is suggested that perhaps the combined action of lime and a legume crop, or possibly other crops, produces an aggregating force which lime alone may not exert. The grasses failed to produce the aggregation of the soil expected of them, but their failure in this experiment may have been due to the shortness of the growth period.

The more aggregated portions of the soil contained significantly more organic carbon than the less aggregated portions. Ultimate particle size in the various size groups of aggregates was quite similar. Hence it is believed these results lend weight to the assignment of an important rôle to organic matter in the aggregation of the mineral particles of soils.

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INFLUENCE OF ARSENICAL TREATMENTS UPON RAPID TESTS FOR SOIL PHOSPHORUS[1]

M. S. ANDERSON AND J. W. BENGTSON[2]

RAPID chemical tests for water-soluble or for available phosphates in soils ordinarily employ the Deniges reaction. The cerulean blue color is produced either by phosphorus or by arsenic. An improved method for determination of either of these elements was described by Truog and Meyer (5)[3] in 1929. When arsenic is distilled over in the form of arsenic tribromide previous to developing the color reaction, phosphorus is of course eliminated as a factor in the test. But, in the rapid soil tests, arsenic as well as phosphorus is dissolved by the reagents, though it is generally assumed that the quantity of arsenic contributing to the color is negligible.

This general assumption is far from the truth in some sections of the country. Arsenic compounds, particularly arsenates of lead and calcium, are widely used in agricultural practices for the control of insects affecting cotton, orchards, and truck crops. After these materials have been used for several years for spraying such crops, considerable arsenic may accumulate in the soil (1).

In the area of Japanese beetle infestation, arsenate of lead is widely used to destroy the insect in its larval stage. The usual rates of application for this purpose are from 200 to 500 pounds of arsenate of lead to the acre. Frequently much higher rates are used, and it is usually necessary to repeat applications every few years. Similar applications of arsenate of lead are frequently used in the control of the larvae of the May beetle or June bug, earthworms, and other pests.

In recent years there has been a decided increase in the use of rapid tests for the determination of the fertilizer requirements of lawns, parks, golf courses, and similar turfed areas. On several occasions it has been observed that the rapid methods used for the testing of soil samples taken from such areas indicated a higher phosphoric acid content than appeared reasonable, judging from fertilizer practice. Since arsenate of lead is so extensively used in such turfed areas it was suspected as a possible source of error. Apparently, no results have been published on the use of rapid phosphorus tests on soils which have received arsenical treatment.

In connection with some experimental work where plats received varying amounts of arsenicals and phosphoric acid it was noted that there was a great irregularity in the available phosphoric acid content of the soil as indicated by one of the rapid chemical tests. Check plat soils showed little or no available phosphate by this test, while soils receiving either arsenical or phosphate treatments showed the presence of an adequate phosphate supply. In these particular plats rela-

[1]Joint contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture and the Greens Section, U. S. Golf Association. Received for publication July 5, 1938.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 846.

TABLE 1.—*Available phosphorus indicated in soils variously treated with fertilizers and arsenicals.*

Lab. No.	Plat No.	Treatment, pounds per 1,000 sq. ft.		Indiana method	Morgan method	Truog method, lbs. per acre
		Total amount added	Applications			
C-3767	8	Check		Very low	Low	12
C-3770	11	1.5 lbs. P_2O_5	3 times, grade 6-3-2, 1936-37	Very low	Low	32
C-3768	9	12 lbs. P_2O_5	3 times, grade 6-24-2, 1936-37	Medium	Medium	168
C-3766	7	5 lbs. arsenic acid	6 times, 1936-37	Low	Medium	80
C-3769	10	5 lbs. arsenic acid 1.5 lbs. P_2O_5	6 times, 1936-37 3 times, grade 6-3-2, 1936-37	Medium	Medium	48
C-3765	6	5 lbs. arsenic acid 12 lbs. P_2O_5	4 times, 1936-37 3 times, grade 6-24-2, 1936-37	High	High	132
C-3761	2	12 lbs. arsenic acid	4 times, 1935-36	Medium	High	80
C-3762	3	12 lbs. arsenic acid	4 times, 1935-36	Medium	High	88
C-3772	13	12 lbs. arsenic acid 3.0 lbs. P_2O_5	6 times, 1934-37 2 times, grade 6-12-4, 1934-35	High	Very high	240
C-3760	1	24 lbs. arsenic acid	3 times, 1935-36	High	High	104
C-3763	4	40 lbs. lead arsenate	4 times, 1933	Very high	Medium	108
C-3764	5	40 lbs. lead arsenate	1 time, 1936	Very high	Low	104
C-3771	12	9 lbs. As_2O_5 3 lbs. P_2O_5	6 times, 1934-37 2 times, grade 6-12-4, 1934-35	High	Very high	264

tively large quantities of arsenic had been applied. However, repeated treatments such as used in field practice would ultimately effect a total accumulation of arsenic comparable to the rates used in these tests.

Further samples were taken from these plats and tested in the laboratory by three of the widely used rapid phosphorus tests developed at different state experiment stations.

The soil extracting solutions employed in these several methods differ widely. The Indiana procedure (3) calls for essentially a 0.1 N hydrochloric acid solution (approximately pH 1.0); the Morgan method (2) prescribes a relatively strong sodium acetate solution with acetic acid added to give it a pH of about 4.8. The Truog extracting solution (4) consists of 0.002 N sulfuric acid buffered with ammonium sulfate at pH 3.0. Ratios of soil and solution also differ in these tests. The results are given in Table 1.

It is evident from Table 1 that the relative quantities of phosphorus or arsenic, or both, dissolved by the different extracting solutions vary somewhat but show the same general trends. It is clear, also, that rapid tests for phosphorus, as ordinarily conducted, are meaningless when soils have received any kind of arsenical treatments. Longer procedures involving a separation of phosphorus and arsenic are essential for furnishing an idea of the phosphorus situation when arsenic has been added.

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RELATIONSHIPS BETWEEN SOME SOIL MEASUREMENTS AND THE INCIDENCE OF THE TWO COMMON POAS[1]

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OUR knowledge of bluegrass ecology is based largely on observations and opinions and only to a slight degree on the results of measurements. It is of course conceded that studied observations of agronomists of training and experience deserve respect until careful experimental work proves them to be inaccurate. This investigation, employing soil analytical methods which are known to have their limitations, is intended only as a step toward replacing crop ecological opinion with something tangible.

Within the humid northeastern portion of the United States, where the dominant pasture grasses are believed to be quite generally Poas, are found areas in which each of the two common species of that genus dominates. An interesting but much involved question is, "Why does *Poa compressa* (Canada bluegrass) dominate in the lake counties of western New York on some of the most agriculturally important soils of the state; while *Poa pratensis* (Kentucky bluegrass) dominates in the Ithaca area on soils not so highly regarded agriculturally?" Popular agronomic opinion would predict the reverse of this.

Most bluegrass pastures in New York are mixed. That is, patches of either species of Poa may be found in pastures where the other dominates. Do such patches reflect soil differences or are they the result of chance? Data contributing to the answers to these questions should be helpful in eventually formulating a sound bluegrass ecology.

REVIEW OF LITERATURE

Results of plat experiments dealing with the difference in fertility levels at which the two common Poas thrive are rare. Numerous ecologists have attempted to correlate the incidence of plants in nature with hydrogen-ion concentration or with presence or absence of calcium carbonate. Salisbury (19)[3] believed that reaction preference was significantly. shown if an occurrence frequency curve displayed a distinct mode. The work of Olsen (17) indicated that factors other than acidity influenced the occurrence of *Poa pratensis* in Danish meadows.

Cooper (2) collected 1868 samples of soil from beneath swards in 546 New York pastures; determined pH potentiometrically, and presented frequency distribution tables for various grasses in 10 pH ranges. Cooper's range for *Poa pratensis* is distinctly broader than Olsen's. Cooper suggested that a well-balanced supply of available cationic and anionic nutrient materials with relatively high oxidation-reduction potentials is much more effective than the hydrogen-ion

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[3]Figures in parenthesis refer to "Literature Cited", p. 860.

concentration of the soil in determining the dominance of various pasture plants.

Steiger (21) observed the effect of physiographic position on the occurrence of Poas in prairie swards. Cooper, Wilson, and Barron (3) expressed belief that various pasture plants tolerate different nutritional complexes. Dix (6) failed to correlate vegetation with certain chemical and physical measurements in 53 old Holstein-Schleswig pastures. Skinner and Noll (20) brought about a change in Poa species dominance under plat conditions, *Poa pratensis* being favored by applications of fertilizer.

Agronomists, too numerous to mention, have expressed the belief, unsupported by experimental evidence, that *Poa pratensis* requires a higher fertility level than *Poa compressa*. Some have been of the opinion that the latter grass is more likely to dominate on acid thin, dry soils of heavy texture.

Analyses made by numerous investigators of the herbage collected from areas where plants may have had opportunity to reflect equilibrium with environment seem to be in agreement on only two points, *viz.*, that *Poa pratensis* is higher in nitrogen (or protein) than *Poa compressa*, and likewise higher in phosphorus.

Scores of investigators have given attention to various phases of cation exchange. Many have concerned themselves with methods of determination. Several have studied the effect of cropping and fertilizing on the exchangeable bases of the soil. However, the investigators who have attempted to correlate replaceable cations with crop response are very few.

The work of Hoagland and Martin (9) and that of Gedroiz (8) make it apparent that exchangeable bases are not the only ones available to plants. The former writers also call attention to the possibility of luxury consumption of nutrients by plants. On the other hand, Fraps (7), Wheeting (22), and Bauer and Snider (1) have found fairly good agreement between replaceable potassium and plant response.

Kelley (11) has pointed out the limitations of cation exchange. From the literature it appears that the measurement of a replaceable base at any one time is not necessarily a measure of the ability of the soil to supply that base, but reflects the net effect of supply together with crop removal.

THE AREAS STUDIED

Typical provinces (or areas) were chosen on two fairly well-known soil types. *Poa pratensis* dominated the vegetation in every pasture examined on the Dunkirk silty clay loam. *Poa compressa* dominated in every day[4] pasture visited on the Ontario loam. The *Poa pratensis* area is located close to Ithaca in Tompkins County. Its soils are of glacial lake origin. They are described by Howe, Buckman, and Lewis (10). The *Poa compressa* province is located west of Rochester in Monroe County. Crabb, et al. (4) state that the soil (Ontario loam) resulted from the weathering of glacial till. Of the two soils, the Ontario loam (*Poa compressa*) province is generally recognized as the more extensive and valuable agriculturally.

Mordoff (16) supplies climatic data for both areas under the headings "Ithaca" and "Brockport." The mean annual precipitation is

[4]Commonly in New York State relatively small pastures are maintained near buildings for night grazing. This obviates the need for the farmer to drive cattle from a distant lot before the morning milking. Such night pastures are often more heavily grazed than day pastures and droppings are more abundant per unit area.

0.24 inch greater in the *Poa compressa* (Rochester) province; but the rainfall from May to September, inclusive, is 1.98 inch greater in the *Poa pratensis* (Ithaca) area. The significance of this difference may possibly be affected by the fact that night pastures of the *Poa compressa* area are dominantly *Poa pratensis*. There was a difference between areas of 0.71 inch in the lightest growing season rainfalls recorded. Mean annual relative humidity at 8 a.m. was about 4% higher in the Ithaca area. Mean annual temperatures differ by 0.2° F. Mean maximum and mean minimum growing season temperatures do not differ significantly. Thus, such a review of climatological data as is possible leaves one not at all certain that climate exerts the major influence on species dominance in these areas.

Nineteen pastures were found suitable for this study on the Dunkirk silty clay loam. The sward of each pasture was dominantly *Poa pratensis*, but numerous various sized patches of *Poa compressa* were always interspersed. These patches permitted the pairing of samples taken close to each other. Thus slope, degree of erosion, depth of surface soil, drainage, direction of exposure, and texture presented the external appearance of being very similar under the swards of the two grasses. No pairing was done unless closeness of grazing was identical Care was taken to avoid spots influenced by the droppings of livestock. No patch of *Poa compressa* that was less than 5 feet in diameter was sampled, and in most cases the spots of this grass were much larger than that No spot was considered to represent either species unless 80% or more of the vegetation (estimated) was made up of the grass under consideration. In no instance was a sample taken where a trace of clover could be found.

On the Ontario loam 20 pastures well suited to the investigation were located. In each case the sward was predominantly *Poa compressa*. The procedure was the same as that outlined above. Avoiding clover was less a problem in this area than in the *Poa pratensis* province.

METHODS

All samples were collected during June 1936. A soil auger was used and the hand employed as a sleeve in such a manner that almost none of the core of soil was lost. Because root penetration was abnormally deep in the more frequently plowed *Poa compressa* pastures, it was regarded advisable to sample uniformly to a depth of 6⅔ inches. The amount of sample depended on the number of opportunities for pairing. The aim was to collect 12 pairs from each pasture, and that objective was realized in all except three or four cases. In no instance were less than nine pairs taken. The borings collected from beneath each species were combined so that there resulted two composite samples from each pasture. Within a period of not over 4 hours from the time of collecting, each composite sample was spread out to air-dry. The dry soil was put through a sieve having circular perforations 1 mm in diameter and stored in stoppered wide-mouthed bottles.

The pH was determined potentiometrically with the quinhydrone electrode, employing a 1:1 soil-water suspension. Readings thus obtained were checked against a bubbling hydrogen electrode in the case of several samples which had a reaction of approximately pH 8.

Exchangeable hydrogen was determined by means of the unpublished method

of Merkle. Ten grams of soil and 50 cc of 10/N calcium acetate (previously adjusted to pH 6.99) were boiled for 5 minutes in a covered 150-ml beaker. Merkle found that boiling resulted in less drift and more accurate readings than could be expected when 72 hours were allowed for reaching equilibrium without heating. After cooling to room temperature, quinhydrone was added and the platinum electrode inserted directly into the beaker, thus forming a half-cell which was set up against the saturated calomel half-cell of the potentiometer. The resistance was then set at a voltage corresponding to pH 7.0 at the existing temperature. Standard lime-water was used to bring the suspension to a value of pH 7.0.

Fifty grams of soil were used for the determination of exchangeable bases. Neutral ammonium acetate was employed as the exchange solution. The amount required to give a calcium-free test for the percolate varied with the sample. The range was from 1,500 ml to 2,400 ml, the average being close to 1,700. From this point the method of determining bases was essentially that of Merkle (15), except that sodium, ammonium, and carbonates were not estimated.

"Available" phosphorus was estimated colorimetrically by the method of Dahlberg and Brown (5) modified according to suggestions of Merkle as follows: A quarter inch square of tinfoil was used instead of the tin rod. Eleven drops of acid solution of ammonium molybdate were used instead of 5 ml of Dahlberg and Brown molybdate reagent. This acid solution of ammonium molybdate was prepared by dissolving 25 grams of ammonium molybdate in 200 ml of distilled water at 60° C. The solution was then mixed with 800 cc of sulfuric acid. The latter had been prepared by diluting 250 cc of concentrated sulfuric acid to 800 and cooling. Distilled water was then used to bring the volume to 1 liter. The resulting solution was stored in a dated brown bottle. Color standards were prepared from potassium dihydrogen phosphate; fresh standards being made up for each group of six unknowns.

Total nitrogen was determined on hundred-mesh soil by the Gunning-Hibbard method modified to include nitrate nitrogen.

Student's method was used in the statistical treatment of the data resulting from the paired composite samples. Love's (12) modification of Student's table served as a basis for the computation of odds. Coefficients of correlation were computed by Spearman's method as outlined by Love (13).

DISCUSSION OF RESULTS

HYDROGEN-ION CONCENTRATION

Contrary to popular belief, the data presented in Tables 1 and 2 show that *Poa compressa* in this study dominates on the more nearly neutral soil type. The mean hydrogen-ion concentration difference between paired composite samples is 9.880×10^{-8} in the *Poa pratensis* area with odds of only 2.6 to 1 against this difference being due to chance alone. Where *Poa compressa* is the dominant grass the mean difference is 1.906×10^{-7} with odds of about 14 to 1. The mean hydrogen-ion concentration is higher in the *Poa compressa* samples from both provinces, but differences would not justify the conclusion that pH may explain species dominance.

REPLACEABLE HYDROGEN

The effect of replaceable hydrogen in any soil depends upon the total exchange capacity and the degree of saturation with cations

TABLE 1.—*Comparative analyses of soils under both species of Poa in the area of Poa pratensis domination.*

Pasture No.*	*Poa compressa*								*Poa pratensis*							
	M. E. per 100 grams of soil					Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.	M. E. per 100 grams of soil					Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.
	Ca	Mg	K	H	Approximate exchange capacity*				Ca	Mg	K	H	Approximate exchange capacity*			
1	3.45	0.75	0.08	1.88	6.16	69.54	5.70	20.0	2.67	0.68	0.24	2.48	6.06	59.05	5.33	20.0
2	5.18	0.94	0.35	1.00	7.47	86.66	6.12	30.0	5.45	1.21	0.37	1.95	8.97	78.26	5.80	30.0
3	3.71	0.50	0.12	1.63	5.95	72.66	5.70	20.0	3.28	0.52	0.22	1.95	5.97	67.33	5.61	30.0
4	4.69	0.73	0.28	0.98	6.68	85.38	5.93	20.0	4.07	1.70	0.55	1.10	7.41	85.23	6.15	30.0
5	3.10	0.50	0.07	2.02	5.68	64.50	5.46	10.0	4.68	0.70	0.35	1.52	7.25	79.06	5.81	30.0
6	3.64	0.58	0.34	1.82	6.38	71.44	6.00	50.0	4.38	0.60	0.40	1.66	7.04	76.45	6.03	50.0
7	3.81	0.37	0.05	0.87	5.09	82.97	6.14	20.0	4.08	0.45	0.11	0.98	5.62	82.63	6.18	10.0
8	4.84	0.49	0.09	0.48	5.89	91.90	6.81	50.0	4.58	0.46	0.14	0.61	5.79	89.51	6.76	50.0
9	2.60	0.29	0.14	2.03	5.06	59.93	5.50	20.0	3.42	0.41	0.02	1.67	5.52	69.75	5.62	30.0
10	3.65	0.17	0.10	2.26	6.17	63.47	5.25	10.0	3.75	0.20	0.25	1.44	5.64	74.45	5.56	20.0
11	2.53	0.50	0.20	2.21	5.44	59.39	5.44	5.0	2.83	0.52	0.24	2.73	6.33	56.82	5.36	5.0
12	1.73	0.60	0.60	1.37	4.29	68.18	6.20	50.0	1.72	0.56	0.52	1.43	4.22	66.10	6.26	70.0
13	2.91	0.69	0.24	1.50	5.34	71.98	5.62	5.0	3.94	0.87	0.24	1.53	6.58	76.79	6.05	10.0
15	6.89	1.79	0.24	sat.	8.91	sat.	6.65	10.0	5.47	1.14	0.31	0.65	7.58	91.41	6.48	20.0
16	3.83	1.21	0.19	0.90	6.13	85.33	6.33	10.0	3.49	1.24	0.22	1.17	6.12	80.85	6.26	20.0
17	4.33	1.47	0.51	1.24	7.54	83.61	6.28	10.0	4.77	1.46	0.56	1.19	7.98	85.06	6.52	10.0
Av.	3.81	0.72	0.22	1.48	6.14			21.25	3.91	0.80	0.28	1.50	6.51			27.19

*Samples Nos. 14, 18, and 19 lost in laboratory fire.
†Totals and averages based on data carried out three decimal places.

TABLE 2.—*Comparative analyses of soils under both species of Poa in the area of Poa compressa domination.*

Pasture No.*	*Poa compressa*: M. E. per 100 grams of soil: Ca	Mg	K	H	Approximate exchange capacity*	Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.	*Poa pratensis*: M. E. per 100 grams of soil: Ca	Mg	K	H	Approximate exchange capacity*	Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.
1	5.87	1.17	0.23	1.27	8.54	85.15	6.40	10.0	7.18	1.57	0.14	1.31	10.20	87.14	6.40	10.0
2	4.88	0.93	0.17	1.93	7.90	75.59	6.11	10.0	4.79	0.93	0.27	1.76	7.75	77.37	6.20	20.0
3	4.90	1.38	0.16	1.52	7.96	80.93	6.48	10.0	8.71	4.64	0.23	1.34	14.93	91.00	6.44	10.0
4	6.00	2.34	0.24	sat.	8.58	sat.	8.11	20.0	6.41	2.14	0.25	sat.	8.79	sat.	8.06	20.0
5	5.64	1.58	0.28	sat.	7.50	sat.	7.46	5.0	7.72	3.01	0.31	sat.	11.05	sat.	7.32	5.0
6	5.77	1.36	0.55	0.90	8.58	89.51	6.93	10.0	5.86	1.59	0.45	0.60	8.50	92.97	6.90	10.0
7	8.30	1.79	0.25	sat.	10.34	sat.	7.88	20.0	7.07	2.02	0.28	sat.	9.38	sat	7.93	50.0
8	5.38	1.58	0.10	0.46	7.51	93.93	6.46	5.0	7.20	1.42	0.43	0.09	9.13	99.05	6.91	5.0
9	8.32	1.73	0.34	sat.	10.39	sat.	7.06	5.0	8.86	1.64	0.47	sat.	10.97	sat.	6.99	30.0
10	9.54	2.11	0.32	sat.	11.97	sat.	7.19	10.0	9.31	2.90	0.46	sat.	12.66	sat.	7.12	50.0
11	7.32	1.51	0.26	0.54	9.62	94.37	6.85	5.0	7.72	1.67	0.47	sat.	9.85	sat.	7.04	10.0
12	11.26	3.04	0.21	sat.	14.52	sat.	7.46	50.0	11.61	3.40	0.23	sat.	15.24	sat.	7.82	50.0
13	7.92	2.13	0.30	0.13	10.48	98.76	6.75	20.0	8.16	2.24	0.30	sat.	10.71	sat.	7.20	20.0
14	11.46	1.44	0.44	1.57	14.90	89.47	5.90	5.0	8.72	1.42	0.36	0.37	10.86	96.60	6.95	5.0
15	7.86	3.59	0.30	0.62	12.37	95.00	6.93	10.0	7.88	4.27	0.26	0.60	13.01	95.42	6.76	10.0
16	6.85	1.41	0.40	sat.	8.66	sat.	7.00	10.0	7.50	2.33	0.41	sat	10.24	sat.	7.06	2.5
17	12.01	2.00	0.34	0.46	14.80	96.92	6.72	5.0	11.54	3.38	0.34	sat.	15.26	sat.	7.05	10.0
18	4.74	1.83	0.35	1.31	8.23	84.06	6.25	10.0	4.83	1.77	0.43	0.92	7.95	88.41	6.52	5.0
20	6.96	4.15	0.25	sat.	11.35	sat.	7.32	5.0	7.65	4.18	0.23	0.11	12.17	99.10	6.96	10.0
Av.	7.42	1.95	0.29	0.97	10.22			11.84	7.83	2.45	0.33	0.79	10.98			17.5

*Sample No. 19 lost in laboratory fire.
†Totals and averages based on data carried out three decimal places

other than hydrogen. Thus, by itself, a figure representing replaceable hydrogen is somewhat incomplete. The writer did not determine replaceable hydrogen in anticipation that it would serve as a means of predicting where either species of Poa is especially adapted, but rather for the sake of completing the exchange picture of the soils.

The data show more replaceable hydrogen in soils taken from the *Poa pratensis* province than in those taken from the one where *Poa compressa* dominates; but again differences between paired samples within either province lack consistency. A mean difference of 0.121 M.E. with odds of approximately 6.5 to 1 is found for the area of *Poa pratensis* and a difference of 0.190 M.E. with odds of about 3.9 to 1 for the *Poa compressa* province. The mean replaceable hydrogen is higher under *Poa pratensis* in the area where that species dominates and higher under *Poa compressa* where it dominates.

The agreement between the pH data and those for replaceable hydrogen is indicated by highly significant coefficients of correlation. (See Table 3)

TABLE 3 —*Correlation data.*

Correlation between	Coefficients			
	Area of *Poa compressa* dominance		Area of *Poa pratensis* dominance	
	P compressa	*P pratensis*	*P compressa*	*P. pratensis*
Total nitrogen and approximate total exchange capacity	.576†	949†	272*	.664†
Total nitrogen and replaceable potassium	.095*	-.176*	445*	354*
Total nitrogen and sodium acetate soluble phosphate	- 170*	144*	275*	-.011*
pH and sodium acetate soluble phosphate	.353*	.397*	.315*	-.011*
pH and percentage saturation	.903†	.929†	.802†	.752†
pH and replaceable hydrogen.	-.828†	-.789†	-.864†	-.646†
Replaceable calcium and sodium acetate soluble phosphate . .	.021*	.272*	.050*	-.135*
Replaceable magnesium and sodium acetate soluble phosphate.	.257*	.050*	-.095*	-.177*

*Means not significant.
†Means highly significant.
Odds 99 to 1, or better.

REPLACEABLE CALCIUM

Failure to determine carbonates[5] influences the validity of the replaceable calcium figures, for, according to Kelley (11) and Gedroiz (8) carbonate calcium is probably available. For this reason the exchangeable calcium data should be regarded as approximate. Since all samples were leached until calcium tests were negative, it is likely that the data more nearly represent available than replaceable calcium.

The figures in Tables 1 and 2 show that the approximate replaceable calcium is generally higher in the province of *Poa compressa* domination than in the area where *Poa pratensis* holds the ascendency. In the former area, 14 of 19 pastures contained more approximate replaceable calcium under *Poa pratensis* than under *Poa compressa.* The mean difference between paired samples is approximately 0.41 M.E. with odds of 11 to 1. The mean difference between paired samples is approximately 0.11 M.E. in the *Poa pratensis* area, with odds of about 2½ to 1. Again in this instance the calcium mean is slightly higher under *Poa pratensis* than under *Poa compressa.*

REPLACEABLE MAGNESIUM

According to Crabb, *et al.* (4), some of the parent rock from which the glaciated Ontario loam was derived was Lockport limestone which is dolomitic. This suggested that if indeed one element might have a major influence on the incidence of either species, magnesium was a possibility. The work of MacIntire, Willis, and Hardy (14) indicated that magnesium carbonate, as such, is not a common constituent of humid region soils.

Tables 1 and 2 show that the area of *Poa compressa* domination is generally higher in exchangeable magnesium than that of *Poa pratensis.* However, within the province of *Poa compressa,* more exchangeable magnesium is found under *Poa pratensis.* Odds pertaining to the mean difference are at least 100 to 1 even when the somewhat dubious looking results of pasture No. 3 are included. (160 to 1 when No. 3 is excluded.) This relationship does not apply to the *Poa pratensis* province where the mean difference (in the same direction) is only about 0.07 M.E. and the odds are about 4 to 1.

One might only speculate as to causes of differences in the replaceable magnesium between paired samples of Ontario loam. Soil variation might have resulted from varying amounts of dolomitic material deposited in glacial debris. It is also possible that the replaceable magnesium was influenced by vegetation over a period of time. *Poa pratensis* makes a more dense sod than *Poa compressa.* The total nitrogen data support the suspicion that residues may be greater under *Poa pratensis.* Residue differences might explain differences in replaceable magnesium. Also livestock droppings of some earlier time may have an effect even though they no longer be visible. Merkle (15) was among those who showed that the use of manure increased exchangeable magnesium.

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[5]Destruction of sample remnants in a laboratory fire made carbonate determinations impossible.

Not enough plant analysis data are available to show a trend in magnesium content characteristic of either species. The improbability that magnesium would be little depleted by a grass in a province where it does not dominate and more depleted by the same grass where it does dominate, leads one back to the hypothesis that the original soil material was different. This hypothesis is somewhat further supported by the data which show that approximate total exchange capacity is not generally greater where more replaceable magnesium is found in the *Poa compressa* province.

Another possible explanation is that replaceable magnesium is taken up less rapidly by the species under which more is found. This cannot be a species characteristic, for if that were the case one would expect the species to influence exchangeable magnesium in a similar direction on both soil types, which is not in accord with the data.

REPLACEABLE POTASSIUM

More consistent differences in exchangeable potassium exist between the paired samples of soils taken from beneath the two species in the province of *Poa pratensis* than between those taken where *Poa compressa* dominates. In the former area, the mean difference between paired samples is 0.071 M E., the *Poa pratensis* soil being higher. The odds are about 105 to 1. Any attempt to explain why such a difference occurs can be no more than speculation. It is rather unlikely that the parent soil material was responsible because the Dunkirk silty clay loam was formed under glacial lake conditions (10).

As was pointed out in the case of magnesium, it is possible that livestock droppings of an earlier time or greater plant residues under *Poa pratensis* might be accountable for differences in replaceable bases. Also, if total nitrogen is assumed to correlate fairly well with organic matter and if decaying organic matter is assumed to affect the liberation of mineral soil potassium, one might expect total nitrogen to fluctuate with exchangeable potassium. That would involve ignoring plant removal and assuming that there is no difference between organic matter and actively decaying organic matter. The coefficients of correlation (Table 3) show that, despite all assumptions, there is no direct significant relationship between total nitrogen and replaceable potassium.

Differences between amounts of replaceable potassium found in the paired composite samples may be due to differences in the absorption of potassium by the Poa species. Herbage analyses reported by various investigators are not consistent enough to indicate that high potassium content is a species characteristic. The possibility of luxury consumption would lead one to expect no general agreement with respect to potassium in herbage analyses.

In the *Poa compressa* province the trend appears to be toward more replaceable potassium under *Poa pratensis*, but the mean difference is only 0.044 M.E. (Odds about 20 to 1.)

Unpublished observations of Cornell extension agronomists include cases of pastures that were dominantly *Poa compressa* being converted to dominantly *Poa pratensis* through the application of

manure. Unpublished research of Dr. J. A. Bizzell of Cornell University calls attention to the potassium content of this farm byproduct. In his work manure was stored in lysimeters over a period of approximately 12 months. The drainage water from this manure was found to contain over three times as much potassium as nitrogen.

There is, no doubt, some difference between the soluble potassium of manure and the replaceable potassium of the soil. However, when one considers the above view points concerning manure along with the exchangeable potassium data, he is reluctant to generalize concerning the influence of potassium on the incidence of Poa species.

APPROXIMATE TOTAL EXCHANGE CAPACITY

The word "approximate" is used in connection with exchange capacity because sodium, ammonium, and carbonates were not determined. The exchange capacity figures which appear in Tables 1 and 2 were obtained by adding together the figures for the various bases. Mean approximate total exchange capacities are higher for *Poa pratensis* in both provinces. A mean difference of 0.759 M.E. with odds of about 14 to 1 is the result for the *Poa compressa* province; while the difference is 0.368 M.E. and odds about 27 to 1 where *Poa pratensis* dominates.

The data used in making Figs. 1 and 2 consistently show more total nitrogen under *Poa pratensis* than under *Poa compressa*. From this one might expect that the organic matter, represented in theory by the nitrogen, would mean higher exchange capacity. That total nitrogen and exchange capacity correlate is shown by coefficients of correlation appearing in Table 3. Note that the correlation is significantly positive except for the *Poa compressa* spots in the *Poa pratensis* province.

APPROXIMATE PERCENTAGE METALLIC BASE SATURATION

Pierre (18) suggested that saturation data might be more significant from the crop standpoint than those pertaining to hydrogen-ion concentration. This is more likely to be true when the data represent several soil types than when they are taken within one type. The results appearing in Tables 1 and 2 are decidedly conflicting. In the *Poa pratensis* area the mean difference between the percentages of saturation of soils from beneath the two species is 0.112 (odds less than 1 to 1).

On the other hand, the mean difference in percentage saturation is 2.176 and the odds over 300 to 1 in the *Poa compressa* area, the greater mean being under *Poa pratensis*. The soils of this area are relatively high in calcium and magnesium and most of them are "saturated" or nearly "saturated".

It is of interest to note the degree of positive correlation between pH and approximate base saturation. Highly significant coefficients are obtained for both grasses for both areas. These may be found in Table 3.

"AVAILABLE" PHOSPHATES

It was not possible to obtain reliable fertilizer histories of most pastures included in this study. Many of them probably never re-

ceived commercial fertilizer. However, pastures 3 to 12, inclusive, in the province of *Poa pratensis* domination were known to have received superphosphate within 5 years. It is probably not without significance that the *Poa compressa* soil samples from pastures Nos. 5, 10, and 11, and the *Poa pratensis* soil from pasture No. 11 were the lowest in "available" phosphates and highest in hydrogen-ion concentration of the soils in the treated group.

In the *Poa pratensis* province pasture No. 12 is located where a garden occurred about 5 years before the time of sampling. Pasture No. 6 was treated with superphosphate approximately a month before the date the samples were taken. These facts, together with the phosphate contents of the soils from the latter two pastures, indicate that the test employed reveals differences somewhat in line with treatment, in at least these two known cases.

From the data in Tables 1 and 2 one may calculate that the mean difference in phosphates between the paired samples from the *Poa pratensis* province is 5.94 pounds per 2,000,000 pounds of soil; the odds about 171 to 1. Where *Poa compressa* is the dominant grass, the mean difference is 5.65 pounds of PO_4 and the odds about 30 to 1. In both areas the greater mean amounts of PO_4 are found under *Poa pratensis*, but the differences were only slightly greater than the precision intervals of the determinations. Thus, the soil phosphate data appear to be in general agreement with plant analysis results published by most investigators working with the Poa species. Attention has been drawn to the probability of greater residues under the more dense sward of *Poa pratensis*. Plant residues could account for phosphate differences. These results, interpreted in the light of the above facts and postulates might help bear out the opinion of agronomists who believe that *Poa pratensis* requires a higher fertility level than *Poa compressa*.

Another supposition that one might make in an effort to explain the greater phosphate content of the soil under *Poa pratensis* is that that species did not take up phosphates to as great an extent as *Poa compressa*. Such a supposition would not be in agreement with plant analysis data.

TOTAL NITROGEN

Of the pastures studied, the only ones known to have received an application of manure within 10 years are Nos. 6, 7, 8, and 12 in the province of *Poa pratensis* domination and No. 4 in the province of *Poa compressa* domination. None of these was treated with manure within 2 years of the time of sampling and none proves to be especially high in total nitrogen. It has been observed by Cornell extension agronomists and by the writer that applications of manure to *Poa compressa* pastures tends to bring in *Poa pratensis*. This tendency is noticeable in *Poa compressa* pasture No. 4 where more than the usual amount of *Poa pratensis* is found.

No pasture included in this study is known to have received any commercial form of nitrogen with the single exception of *Poa pratensis* pasture No. 12, and it had not received commercial nitrogen within 5 years of the time of sampling. *Poa pratensis* pastures Nos. 3, 4, and 5

were seeded in 1931. The sweet clover which served as a nurse crop was grazed in 1932. The data show that these pastures are not perceptibly higher in total nitrogen than others where sweet clover had not been grown.

In the area of *Poa pratensis* domination the mean total nitrogen is 0.0321% higher under *Poa pratensis* than under *Poa compressa* (odds 3,332 to 1). Where *Poa compressa* dominates, mean total nitrogen is 0.0523% higher under *Poa pratensis* than under *Poa compressa* (odds infinite). Figs. 1 and 2 illustrate how consistent the nitrogen differences are.

Again the data appear to be in agreement with the majority of plant analysis figures to be found in the literature, and also in agreement with the views of numerous observers who have contended that *Poa pratensis* requires a higher fertility level than *Poa compressa*. The total nitrogen data also help make it possible for the writer to understand why there may be found in the *Poa compressa* province certain night pastures which are close to 100% *Poa pratensis*. However, it cannot be said from this investigation whether the total nitrogen figures, which in a general way reflect organic matter, should be interpreted to mean that nitrogen is responsible (together with phosphorus) for the incidence of *Poa pratensis*, or whether some property of the organic matter is accountable to a greater degree. One of these properties of the assumed organic matter is the moisture-holding capacity; another is its possible effect on soil temperature. Of course the moisture aspect of the problem would involve a subsoil study which has not been made.

The data do not enable one to distinguish between cause and effect. In other words they do not indicate whether total nitrogen directly contributes to influence the incidence of the Poas, or whether total nitrogen differences are the result of residues caused by unlike sod-forming habits of the two species.

Although no soil sample was taken where even so much as a trace of clover was visible, it cannot be said that clover had not occurred at some previous time in the patches, usually of *Poa pratensis*, where total nitrogen content is relatively high. The greater phosphate content of the *Poa pratensis* spots might easily have favored legume growth. What has been said about clover influence might also be said about feces and urine, although sampling patches 5 feet and more in diameter may make this supposition a little less likely.

The work of Skinner and Noll (20) which showed the influence of nitrogen on the transition from *Poa compressa* to *Poa pratensis* would lend weight to the belief that nitrogen had a causal effect. However, in the investigation of these workers, phosphorus and potash tended to bring about a similar transition. It is possible that the latter two elements accomplished this result indirectly through the stimulation of clover which was present under the conditions of their work.

SUMMARY

Thirty-nine New York pastures were chosen for study in two localities not vastly different in climate but distinctly unlike in soil. In the more agriculturally important Ontario loam area or province

Poa compressa is the dominant grass, while *Poa pratensis* holds the ascendency in the area on Dunkirk silty clay loam. Patches of the species other than the dominant one occurred in all pastures selected for study. This made possible the pairing of samples and the use of Student's method. This investigation considers soil differences beneath the two species of Poa, on which subject there are many opinions and few experimental data.

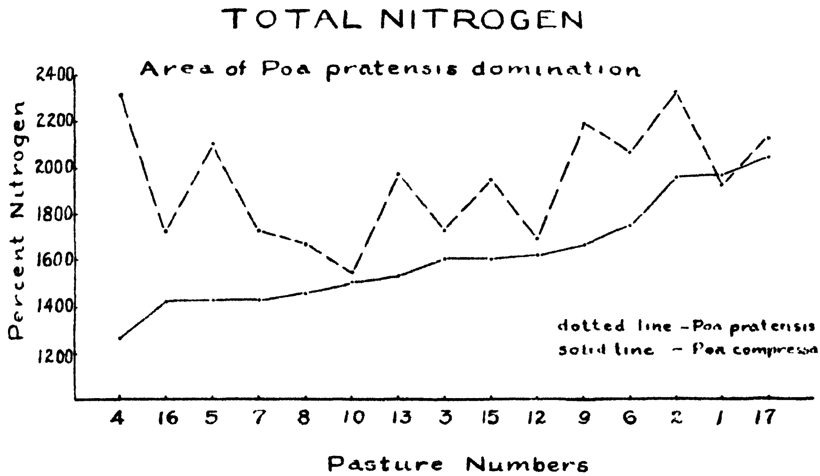

FIG. 1

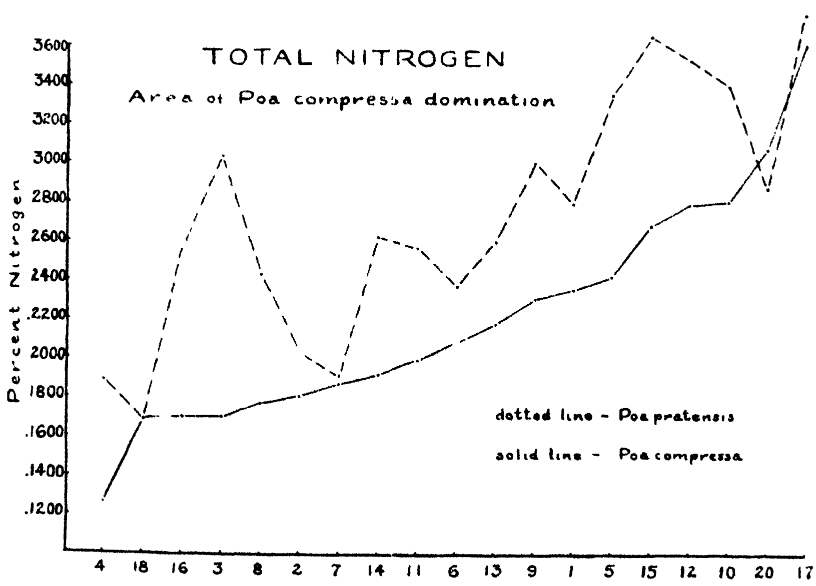

FIG. 2.

The hydrogen-ion concentration results support odds of about 2.6 to 1 and about 14 to 1, respectively, for the mean differences between the paired soil samples from beneath the two species in the *Poa pratensis* and *Poa compressa* provinces. Despite this, and contrary to popular opinion, *Poa compressa* dominates in the province of lower hydrogen-ion concentration (or higher pH).

Data for replaceable hydrogen agree generally with the pH figures as indicated by significant negative coefficients of correlation.

Odds for the mean differences in approximate replaceable calcium are about 6.1 to 1 and about 3.9 to 1 for the areas of the *pratensis* and *compressa* species, respectively. However, it is very evident from the data that *Poa compressa* dominates in the province the soil of which is generally higher in replaceable calcium.

Within the province of *Poa compressa* domination the means indicate more replaceable magnesium under the *pratensis* species than under *compressa*. Odds for the mean difference are at least 100 to 1. In the *Poa pratensis* province the mean difference (in the same direction) justifies odds of 4 to 1.

Mean differences in replaceable potassium seem, in a sense, to be the counterpart of those for magnesium. The higher odds (about 105 to 1) apply to the *Poa pratensis* province. Odds for the *Poa compressa* area are about 20 to 1. In both cases the means are higher under the *pratensis* species.

Differences between approximate total exchange capacity means yield odds of about 27 to 1 and about 14 to 1 for the areas of *Poa pratensis* and *Poa compressa*, respectively. A high degree of positive correlation exists between total nitrogen and approximate total exchange capacity except for the *Poa compressa* soils taken in the *Poa pratensis* area.

Mean approximate metallic base saturation is higher for soils beneath the *pratensis* species than beneath those of the *compressa* in the area where the latter is dominant. Odds for the mean difference are over 300 to 1. In the *Poa pratensis* area the odds are less than 1 to 1. There is a high degree of positive correlation between pH and metallic base saturation.

More "available" phosphates are generally found under the *pratensis* in both provinces, but the mean differences are only slightly greater than the precision intervals of the determinations. Odds are about 171 to 1 and 30 to 1 for *Poa pratensis* and *Poa compressa* areas, respectively.

Infinite odds and odds of about 3,332 to 1 between means for the areas of *Poa compressa* and *Poa pratensis*, respectively, indicate that greater amounts of total nitrogen are found under *Poa pratensis*.

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IMPROVEMENT OF *ANDROPOGON SCOPARIUS* MICHX. BY BREEDING AND SELECTION[1]

KLING ANDERSON AND A. E. ALDOUS[2]

ANDROPOGON SCOPARIUS is widely distributed over the temperate portion of North America, its range, according to Hitchcock (6),[3] extending from Quebec and Maine to Alberta and Idaho and from there southward to Florida and Arizona. It is of major importance, however, only in the tall grass or true prairie region. Weaver and Fitzpatrick (12) rate it as the second most important species of the prairie, second only to *Andropogon furcatus*. These two species make up approximately half the total vegetative cover of the Flint Hill or bluestem pasture region, which is the only remaining large area of these grasses.

Drought and overgrazing have so seriously depleted the ranges that it is now necessary that something be done to restore them. To this end the plant breeder can play an important part in the production of superior strains. Before this can be done, however, knowledge of the variability and inheritance of the characters with which he is to work must be available. To this end, studies of *Andropogon scoparius* were started in 1935 by the Agronomy Department of Kansas State College.

REVIEW OF LITERATURE

Andropogon scoparius, like many other species, is extremely variable, being made up of a number of habitat types corresponding to Turesson's (11) ecotypes. Gregor and Sansome (4) conclude that there exist within a species definite habitat types and agree with Turesson that these types represent the genotypical response of the species-population to a definite habitat. They further state that there may be phenotypic uniformity within these habitat types without complete genotypic similarity; or in the words of Turesson (10), "The habitat type, even if it appear to be quite homogeneous in its habitat, is made up of a number of individuals, none of which may represent the genotype of another".

Jenkin (7) in his work with *Lolium perenne* has noted that individual plants differ from one another even when derived from a relatively stable habitat, but that this variation is usually within quite narrow limits, while plants from different habitats conform to different general types.

The behavior of its chromosomes at meiosis may afford some explanation of the variability of *Andropogon scoparius* within these habitat types. Church (3) reports that this species is an octoploid having the unusual chromosome complement of 21 bivalents and 14 univalents. During the metaphase of the first division, the univalents may be seen lagging in contrast with the bivalents all at the plate, and in the partly completed anaphase it can be seen that many of them never reach the plate. The diad stage may be observed with extrusions of chromatin stranded in the space between the separating halves of the mother cell. Bivalents

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[3]Figures in parenthesis refer to "Literature Cited", p. 869.

may occasionally lag with the univalents in the homeotypic division. The distribution of the univalents to the two daughter cells is random.

Selfing apparently reduces the set of seed in this species just as it does in a number of other grasses that have been studied. Beddows (1) obtained 22.3 times as many seeds from open-pollinated heads of *Festuca elatior* as from those enclosed in selfing bags. Hayes and Barker (5) found low seed set in selfed heads of timothy. Jenkin (7) not only found a reduction in seed set but found many highly self-sterile plants of *Lolium perenne*. He believes that this self-sterility is one of the greatest obstacles in the way of improvement of grasses.

The vigor of open-pollinated crops is generally depressed in the generations following inbreeding. Jenkin (7) found that cross-fertilization gave an increase of 37 to 224% in productivity over the inbred progenies in *Lolium perenne*. Other workers reporting losses in vigor due to inbreeding are Calder (2) in orchard grass, Lewitsky (8) in timothy and red clover, Nilsson-Leissner (9) in red fescue (*Festuca rubra*), and Williams (13) in red clover. Williams showed that some families do not suffer so great losses of vigor as do others. These are valuable for the production of improved strains because they tend to be strongly prepotent for high yielding qualities when outcrossed. He suggests that linked groups of growth factors, inherited as units, may account for the prepotence of some plants.

MATERIALS AND METHODS

Three generations of *Andropogon scoparius* have been included in this study. The first generation, set out in 1935, consisted of 180 plants selected as the most desirable of several hundred seedlings. In a sense this first generation represented the variations that occur in the bluestem pasture region, yet in reality some selection had already been practiced, for the seed from which this generation was grown came from the best plants in the older observation plats of the grass nursery. These in turn had been grown from the seed of particularly promising plants occurring in nature.

The second generation consisted of progeny of each of these plants, while the third generation consisted of progeny of approximately 50 of the best second generation plants. The three generations shall be referred to as the 1935, the 1936, and the 1937 nurseries, respectively.

Each generation of seedlings has been grown in the greenhouse from late February until May when they were transplanted to the nursery. The plants have all been spaced 30 inches in each direction in order that they might attain their full development reasonably unhampered by the competition of neighboring plants, and that they might easily be observed and studied. This spacing also permits easy cultivation with a small horse-drawn cultivator and permits furrow irrigation during the drier months of the summer.

The plants have been carefully observed during the growing season and detailed field notes have been taken. On the basis of these observations the outstanding plants have been selected each year to be the maternal parents of the next generation. A number of heads on each of several particularly promising plants have been bagged so that the effect of selfing might be observed. These heads mature within the bags and are harvested in October at the same time the open-pollinated seed is gathered.

Germination tests have been made during February. The 1936 seed was germinated on moist filter paper in Petri dishes. This gave somewhat higher germination percentages than in the field, so the 1937 seed was germinated on soil in the

greenhouse to simulate natural conditions. It was placed on moist soil and covered with a quarter of an inch of clean sand. After germination counts had been made the seedlings were spaced in greenhouse flats, later to be moved to the nursery.

EXPERIMENTAL RESULTS

GENERAL VARIABILITY

In such a widely distributed species as *Andropogon scoparius* extensive variations are expected to occur. There seem to be rather definite habitat types, corresponding to Turesson's (10) ecotypes, that have arisen as a result of natural selection over long periods of time. Habitat types from North Dakota, Nebraska, Kansas, Oklahoma, and Texas have been grown and observed in the nursery. In general the northern types are earlier, smaller, and less leafy than those from the south. In the 1937 season the average heading date of plants from northern Nebraska was 17 days earlier than that of plants from Manhattan, Kansas, while Oklahoma plants headed 10 days later than those from Manhattan. Variations equally as great are seen in leafiness and plant size. Figs. 1, 2, and 3 serve to illustrate this.

FIG. 1.—*Andropogon scoparius* grown at Manhattan, Kansas, from northern Nebraska seed. Photographed Oct. 6, 1937.

FIG. 2.—*Andropogon scoparius* grown at Manhattan, Kansas, from local seed. Photographed Oct. 6, 1937.

It is not meant to imply that there is complete uniformity within the habitat types, but simply that the variation between types is greater than that within types. When the habitat types are studied more closely they are found to be quite variable within themselves, certain characters such as leafiness, time of maturity, plant height, and seed set, showing wide variations.

LEAFINESS

Since it is the leafy portion of the grass plant that is preferred by the grazing animal, the area of leaf surface may be considered one of the most important factors of quality. On this assumption leaf area has been used as one of the bases of comparison. It is the most important single consideration in the selection of desirable types

Leaf areas were calculated for individual plants by multiplying average length of leaf by average width, by average number of leaves per culm, by total number of culms per plant. This gave a value slightly greater than actual leaf area but which was found to be quite satisfactory for purposes of comparison.

FIG. 3.—*Andropogon scoparius* grown at Manhattan, Kansas, from Oklahoma seed. Photographed Oct. 6, 1937.

The plants have been found to vary greatly in total leaf area. Table 1 shows the leaf areas of the 1937 crop of the three generations.

If this variability in leaf area is due to the genetic constitution, as the results of selection indicate, it may be used as a basis of improvement. The leafy types may be isolated and made uniform by selection and inbreeding, then if necessary they may be blended into strains by hybridization.

TABLE 1.—*Leaf areas per plant (in sq. cm.) of three generations of Andropogon scoparius, measurements taken June, 1937.*

Season of growth	Leaf area in sq. cm.	
	Range	Average and standard deviation
3rd (1935 nursery)	14,000–45,000	30,700±7,500
2nd (1936 nursery)	2,000–24,000	10,000±3,700
1st (1937 nursery)	1,000–15,000	6,500±2,400
1st (1937 nursery—selfed)	1,000–11,000	6,400±2,200

Selection tends to decrease the variability of leaf area in *A. scoparius*. Variations of leaf areas within groups of progeny of individual plants have been found by analysis of variance to be significantly less than the variations between these groups. In these analyses the F values of 3.74 and 7.30 were obtained in the second and third generations, respectively, while the 1% level of significance was only 2.00. This indicates that the variability is actually due, in large part,

to genetic differences in the plant and that improvement can be brought about by selection and breeding.

BASAL DIAMETER, PLANT HEIGHT, AND TIME OF MATURITY

Other variable characters have been found to respond to selection in the same manner as does leaf area. The variations within progeny of single selected individuals have been compared by analysis of variance with the variations between these groups of progeny in the following characters: Basal diameter of plant, plant height, and time of maturity. In each of these characters selection has significantly reduced the variability within groups of progeny. This reduction in variability was particularly pronounced in time of maturity. The average heading date of the second generation (1936 nursery) was August 8±13 days. The next generation, selected for late maturity, headed on September 5±5 days. In both generations variability was significantly less within progeny groups than between them, the F values being 3.20 and 13.37 for the second and third generation, respectively. The 1% level of significance was 2.00. It will be seen that selection not only reduced variability but changed the time of maturity in the desired direction.

SEED SET

Seed set in *Andropogon scoparius* has been studied on the basis of the percentage of spikelets that produce caryopses. Variability has been noted in this character, the average seed set of open-pollinated plants being 63.12±18.7% for the third generation. A great reduction in seed set has been observed when the heads are enclosed in any sort of bag for the purpose of self-fertilization. Under such conditions the seed set was only 6.7±5.3%. It has not been definitely determined, but it is believed that this reduction in seed set is due to the abnormal conditions existing within the selfing bag. It was noted that in bags which had accidentally been torn or had been injured by grasshoppers there was practically a normal set of seed. It was impossible to determine whether or not the bags had been torn before pollination had taken place, so the plants may or may not actually have been selfed.

GERMINATION

This character is important because of the obvious relationship it bears to securing stands. As a rule the germination of *A. scoparius* is fairly high but considerable variation has been observed, as shown in Table 2.

TABLE 2.—*Germination percentages of A. scoparius, 1937 nursery, 1937 crop.*

Year	Pollination method	Germination percentage
1936	Open-pollinated	63.5±13.4
	Selfed	25.8±23.4
1937	Open-pollinated	18.5±12.8
	Selfed	30.5±24.4

The high germination percentages obtained for the 1936 seed, especially the open-pollinated seed, was thought to be due to the fact that the seeds were germinated in the laboratory on moist filter paper, so the 1937 crop was germinated on soil to simulate natural conditions. The germination of the open-pollinated seed was significantly decreased, but there is no way of explaining the fact that there was no corresponding decrease in the case of the selfed seed. Tests of several generations may be necessary to make this clear.

INTERRELATIONSHIPS OF CHARACTERS

It has been observed that rather definite interrelationships exist between certain characters and that they follow definite trends. Table 3 is a summary of these interrelationships.

TABLE 3.—*Correlation coefficients for the interrelationships existing between certain characters of A. scoparius based on data from the 1937 crop of three generations of plants.*

Character observed	Generation in nursery	Number of culms per plant	Height of plant	Leaf area	Time of maturity
Basal diameter of plant	1935	.25±.06	.69±.04	.24±.06	—
	1936	.52±.04	.40±.05	.50±.04	—
	1937	.68±.03	.51±.04	.67±.04	—
Number of culms per plant	1935	—	—	.46±.12	—
	1936	—	—	.79±.02	—
	1937	—	—	.87±.01	—
Height of plant	1935	—	—	.56±.10	—
	1936	—	—	.43±.04	—
	1937	—	—	.31±.05	—
Leaf area	1935	—	—	—	.26 ±.05
	1936	—	—	—	.18 ±.06
	1937	—	—	—	.003±.05

Two factors may be considered to influence these trends, the effect of selection and the effect of the age of the plant, that is, changes brought about during its life cycle. The two effects, however, can not be separated on the basis of the available data.

EFFECTS OF SELF-FERTILIZATION

The data available on the effect of selfing *A. scoparius* are too limited to furnish conclusive evidence. Approximately 50 plants were grown in the 1937 nursery from selfed seed and the evidence from these indicates that selfing has no deleterious effect on any of the characters, except seed set, and its effect on this character is probably due to the abnormal growing conditions existing within the selfing bag. Leaf area, basal diameter, plant height, and germination were not significantly different in the selfed plants when compared with the open-pollinated ones. Should it be shown conclusively that selfing does not reduce vigor in *A. scoparius*, it will prove a valuable method of breeding.

SUMMARY AND CONCLUSIONS

1. *Andropogon scoparius* in nature is an extremely variable species, divided into rather definite habitat types (the ecotypes of Turesson), which, however, exhibit considerable variability within themselves. In general, northern types are earlier, less leafy, and smaller than types from farther south.

2. Leaf area is the best single measure of quality and yield of forage. Wide variations in total leaf areas exist that are due to genetic differences in the plant. This is shown by the fact that the progeny of individual plants vary significantly from the progeny of other plants. The variability between these groups is greater than the variability within them. This indicates that selection, even in open-pollinated populations, tends to increase uniformity.

3. No satisfactory measure of quality has yet been devised. Grazing tests are probably the best measure and shall be applied before final selection of strains is made.

4. Basal diameter of the plants varies widely, yet there is a tendency toward uniformity within groups of progeny of individual plants.

5. Plant height has not been an important factor in selection of superior types of plants, yet studies indicate it to be definitely influenced by genetic make-up. There is a marked uniformity within the progeny of selected plants.

6. It is indicated that time of maturity can be changed by selection. This will make it possible to produce a strain that heads later, hence gives a longer summer grazing season. It is important that time of maturity be as late as possible, yet not so late that plants are frosted before producing seed.

7. Seed set is reduced by selfing in *Andropogon scoparius*. It is not definitely known whether this reduction in seed set is due to genetic causes or to abnormal conditions within the selfing bags.

8. There is no evidence to indicate that selfing has any effect on germination for selfed seed has been found to have as high germination percentages as that from open-pollinated plants.

9. Differences have been observed in rate of germination. It is important that grasses should germinate quickly in order that the seedling plant become established before summer droughts. Seedlings that become established quickly are better able to compete with weeds and other grasses.

10. Rather definite relationships have been found to exist between certain characters in *Andropogon scoparius*, and that these relationships follow definite trends is indicated as follows:

(a) Basal diameter is correlated positively with number of culms, with a tendency for the correlation to be higher in younger plants.

(b) Basal diameter is also correlated positively with plant height but no trends can be observed. Since these characters are expression of general vigor their high positive correlation is in accordance with expectations.

(c) Basal diameter and leaf area are positively correlated, the highest correlation existing in young plants.
(d) Height of plant and leaf area, while positively correlated, exhibit the highest correlation in older plants. Evidence indicates, however, that the low correlation in the third generation may be due to the effect of selection rather than to age of plants.
(e) In general, late plants tend to be leafier than early plants. After two generations of selection, however, no correlation exists between these two characters.

11. The limited amount of evidence on the effect of self-fertilization indicates that the vigor of *Andropogon scoparius* is not seriously, if at all, affected by inbreeding.

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EFFECT OF SEED DISINFECTION AND DELAYED SOWING ON THE CONTROL OF BUNT IN INFESTED SOIL[1]

J. FOSTER MARTIN[2]

CONSIDERABLE infestation by bunt spores (*Tilletia tritici* (Bjerk.) Wint. and *T. levis* Kuhn) sometimes occurs in the soils of the Columbia Basin region, although the introduction of resistant varieties of wheat and more efficient seed treatment methods have significantly reduced the hazard from bunt. Susceptible varieties frequently develop 1 to 10% or more of infected heads when sown in fields in which the soil is infested with bunt spores despite the use of clean and carefully disinfected seed.

In dry years, there is not sufficient soil moisture to germinate all soil-borne bunt spores before the desirable time for fall sowing arrives, although occasionally the soil may be moist enough to sprout wheat. Bunt infection usually is low in wheat sown early when the soil temperature is high. Some farmers in districts of eastern Oregon where bunt infection is unusually heavy take advantage of this situation and sow wheat before fall rains begin, in spite of the hazard of thin stands that may result from the consequent deep sowing in a dry seedbed. If, by delaying sowing for 2 or 3 weeks after the advent of fall rains, soil infestation could be reduced sufficiently for bunt infection to be controlled by seed disinfection, the improvement in stands and better control of weeds as compared with early dry seeding should be of material benefit to farmers. With this in mind, experiments were begun at Pendleton, Ore., in 1931 to determine (a) the relative efficiency of certain seed disinfectants in preventing infection from bunt in the soil, and (b) the length of time sowing must be delayed after the beginning of favorable moisture conditions in the fall to permit the germination and destruction of sufficient soil-borne bunt spores so that resulting infection will be at a minimum. Results of 4 years' experiments are reported here.

REVIEW OF LITERATURE

As early as 1907, Sutton and Pridham (9)[3] noted the value of copper sulfate in protecting seed from recontamination by soil-borne bunt spores. Heald, Zundel, and Boyle (5) stated that 3 ounces of copper carbonate per bushel gave equal or better protection than copper sulfate, but that 2 ounces was not quite so effective. Leukel (7) and Heald and Gaines (4) concluded that these two disinfectants were about equal in fungicidal value. In the experiments of Twentyman (10), however, copper sulfate was superior to copper carbonate in preventing reinfection. Twentyman treated the seed and then re-inoculated it before sowing. In the experiments of Sutton and Pridham (9), Heald, Zundel, and Boyle (5), Heald and Gaines (4),

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[3]Figures in parenthesis refer to "Literature Cited", p. 876.

Twentyman (10), and Leukel (7), formaldehyde gave slight or no protection from reinfection in the soil.

Mackie (8) stated that a minimum of about 14% of soil moisture was necessary for the germination of bunt spores in the soil at Davis, Calif. Heald and Gaines (4) observed that no bunt developed with 12% moisture at Pullman, Wash. However, as noted by the same authors (8, 4), soil may be moist enough to sprout wheat although too dry to germinate the bunt spores. Hungerford (6) and Heald and Gaines (4) reported that in the soils of the Palouse section the optimum soil moisture content for bunt infection was about 25%. Woolman and Humphrey (13) and Leukel (7) call attention to the inhibiting effect of a saturated soil on the germination of bunt spores.

Twentyman (11) reported low percentages of bunt in wheat sown early when the soil was still warm. Woolman (12) found that a practically bunt-free crop was produced when the soil temperature was above 65° F, that the percentage of bunt increased as the temperature fell from 60° to 45° at which point it was highest, and that the infection decreased below 40°. Similar conclusions were drawn by Heald and Gaines (4). According to Faris (2), a temperature of 41° to 59° F is well within the range of high infection. Hungerford (6) obtained the most infection with a temperature of 48° to 54° F. Aamodt (1) and Leukel (7) observed the greatest infection when the soil temperature was 50°. Leukel obtained no infection from *Tilletia tritici* with a soil temperature above 59° and none from *T. levis* above 68°.

According to Hungerford (6), bunt spores which had been in moist cultivated soil for 1 month had practically lost their viability. Heald (3) stated that spores lose their power to infect after 50 to 60 days in moist soil. Woolman and Humphrey (13) found that spores in moist soil lost their infective properties in 30 to 60 days.

MATERIALS AND METHODS

Heavy soil infestation was obtained by scattering 30 grams of bunt spores (*Tilletia tritici* and *T. levis*) per 8-foot row in open furrows, and then mixing the spores with the surface 2 inches of soil. The first sowing was made immediately, after which the entire plat was thoroughly watered. An attempt was made to maintain the soil moisture at approximately 25%, but precipitation on several occasions increased the soil moisture to a point probably above the optimum for bunt infection.

Soil temperature records were kept during the fall of 1934, and they agreed well with the air temperatures except that they did not fluctuate so much or drop so low. The air temperature records seem adequate for explaining certain of the fluctuations in infection data.

All of the materials used for treatment were standard seed disinfectants with the exception of the ethyl mercury iodide. This substance as applied contained 5% of the volatile compound ethyl mercury iodide. Unless otherwise stated, the seed was disinfected 24 hours before sowing.

A single 8-foot row of each treatment was sown on each date and clean seed of the Hybrid 128 variety of wheat was used in all experiments.

RESULTS OBTAINED

RELATIVE EFFECTIVENESS OF SEED DISINFECTANTS

As shown in Table 1 no seed treatment controlled bunt entirely except in two very late plantings in 1934–35 when infection in the untreated rows was less than 5%. The best treatments greatly re-

TABLE 1.—*Bunt infection in Hybrid 128 wheat grown from seed treated with various disinfectants and sown at intervals in soil artificially inoculated with bunt spores in four crop years.*

Date		Seed treatment and bunt infection								
Sown	Emerged	Check, not treated, bunted heads, %	New Improved Ceresan		Ethyl mercury iodide		Copper carbonate		Copper sulfate* bunted heads, %	Formaldehyde† bunted heads, %
			Rate per bu., oz.	Bunted heads, %	Rate per bu., oz.	Bunted heads, %	Rate per bu., oz.	Bunted heads, %		
					1931–32					
Oct. 3	Oct. 13	15.7	—	—	—	—	4	7.6	—	—
Oct. 12	Oct. 21	73.3	—	—	—	—	4	58.8	—	—
Oct. 19	Oct. 29	75.6	—	—	—	—	4	62.4	—	—
Oct. 27	Nov. 5	77.7	—	—	—	—	4	71.1	—	—
Nov. 4	Nov. 15	36.4	—	—	—	—	4	3.7	—	—
Nov. 12	Nov. 27	13.1	—	—	—	—	4	1.1	—	—
Average		48.6	—	—	—	—	—	34.1	—	—
					1933–34					
Nov. 3	Late winter	89.9	3	18.8	—	—	4	62.5	56.8	50.7
Nov. 8	Late winter	93.5	3	33.9	—	—	4	58.9	61.4	57.8
Nov. 17	Late winter	93.2	3	40.7	—	—	4	68.3	63.4	73.7
Nov. 23	Late winter	88.8	3	—	—	—	4	51.9	—	—
Average‡		92.2	—	31.1	—	—	—	63.2	60.5	60.7
					1934–35					
Sept. 19	Sept. 30	11.6	3	10.1	—	—	3	11.2	—	24.9
Sept. 26	Oct. 5	46.8	3	4.9	—	—	3	22.6	—	44.7
Oct. 3	Oct. 14	27.2	3	1.3	—	—	3	32.7	—	24.6
Oct. 10	Oct. 24	60.1	3	1.9	—	—	3	45.8	—	55.4
Oct. 17	Oct. 29	43.6	3	17.4	—	—	3	26.8	—	47.4
Oct. 24	Nov. 7	50.3	3	14.4	—	—	3	32.1	—	33.5
Oct. 31	Nov. 15	40.1	3	18.0	—	—	3	31.6	—	41.4
Nov. 8	Dec.	10.1	3	6.3	—	—	3	3.7	—	9.3
Nov. 15	Dec.	4.2	3	0	—	—	3	4.7	—	0
Feb. 27	Mar. 23	0	3	0	0	—	3	0	—	0
Average		29.4	—	7.4	—	—	—	21.1	—	28.1

1935–36										
Sept. 20	Sept. 27	26.7	½	18.1	½	5.5	3	11.3	—	34.3
Sept. 20	Sept. 27	—	1	14.0	1	17.6	—	—	—	—
Sept. 20	Sept. 27	—	2	10.3	2	9.3	—	—	—	—
Sept. 30	Oct. 8	72.5	½	32.5	½	40.0	3	69.8	—	51.1
Sept. 30	Oct. 8	—	½§	35.2	½§	49.0	—	—	—	—
Sept. 30	Oct. 8	—	1	33.6	1	35.3	—	—	—	—
Sept. 30	Oct. 8	—	1§	36.2	1§	47.1	—	—	—	—
Sept. 30	Oct. 8	—	2§	25.5	2§	46.0	—	—	—	—
Oct. 9	Oct. 19	55.5	½	30.7	½	35.4	3	39.1	—	53.5
Oct. 9	Oct. 19	—	½§	27.2	½§	27.2	—	—	—	—
Oct. 9	Oct. 19	—	1	26.3	1	38.0	—	—	—	—
Oct. 9	Oct. 19	—	1§	35.1	1§	49.4	—	—	—	—
Oct. 9	Oct. 19	—	2§	38.8	2§	49.4	—	—	—	—
Oct. 20	Dec. 8	70.2	½	36.1	—	—	3	71.4	—	—
Oct. 20	Dec. 8	—	1	32.0	—	—	—	—	—	—
Nov. 11	Jan. 10	49.6	½	8.5	—	—	3	27.6	—	—
Nov. 11	Jan. 10	—	1	7.8	—	—	—	—	—	—
Nov. 23	Jan. 10	7.3	½	2.0	—	—	3	2.7	—	—
Nov. 23	Jan. 10	—	1	1.7	—	—	—	—	—	—
Average‖		51.6	—	27.1¶	—	27.0¶	—	40.1	—	46.3

*One pound of copper sulfate to 5 gallons of water, followed by a lime bath
†Solution made up of 1 part formaldehyde to 384 parts water
‡Data not included from rows sown on Nov. 23.
§Seed treated on Sept. 19.
‖Computed from data from first three seedings only.
¶Average for ½-ounce rate of application.

duced the bunt in some of the sowings. The quantity of inoculum in the soil was extremely heavy and better control with fungicides might have been obtained under natural "smut-shower" conditions. No data on this point were obtained in these experiments, however.

New Improved Ceresan was significantly superior to the other standard seed disinfectants in controlling bunt in each of the 3 years they were tested. At the ½-ounce rate of application usually recommended for New Improved Ceresan, the reduction in bunt infection compared with the check in 1935-36 was 47.5%.

Ethyl mercury iodide controlled bunt about as well as New Improved Ceresan when sowing was not delayed. It reduced the average infection by 47.7% in 1936, when applied at ½ ounce per bushel This compound is more volatile than New Improved Ceresan, however, and a distinct decline in effectiveness was noted when 10 days had elapsed between seed treatment and sowing.

Results with copper carbonate and copper sulfate agree in general with those of other investigators. The average reduction in bunt infection by copper carbonate was 29.8, 31.5, 28.2, and 22.3 percent, respectively, for the 4 years of the trial. Four ounces per bushel were applied in 1931-32 and 1933-34, but only 3 ounces per bushel were used the last 2 years. A 2-ounce rate was not included in these tests, as other trials have shown that this is not sufficient to control bunt consistently in a susceptible winter wheat variety in eastern Oregon.

Copper sulfate was tested only in the year 1933-34, but it reduced infection 34.4% compared with 31.5% for copper carbonate in the same year.

Formaldehyde controlled bunt approximately as well as copper carbonate and copper sulfate in 1933-34, but these results were not substantiated in the next two seasons. Formaldehyde reduced the average infection by 34.2, 4.4, and 10.3%, respectively, in the 3 years. The reason for the better control in 1933-34 is not known, but it occurred in all three dates of sowing that year. Emergence was slow and temperatures were equally favorable for high infection in all cases.

New Improved Ceresan was applied at several rates. As stated above, bunt infection was reduced 47.5% by the ½-ounce rate. The infection was reduced 52.3% when 1 ounce per bushel was used. On the average, the 2-ounce rate was superior to the lighter applications, but this rate sometimes is injurious to germination. When applied at 3 ounces per bushel in 1933-34 and 1934-35, it reduced infection 66.3 and 74.8%, respectively, calculated on the basis of infection in the untreated rows as 100%. Unless growing conditions are particularly favorable, however, this heavy rate of application causes a marked reduction in the germination of wheat. There is some, though probably not significant, evidence that New Improved Ceresan applied to the seed became less effective against soil-borne bunt spores when sowing was delayed unduly after treatment. At the 1-ounce rate of application, the crop from seed treated 3 weeks before sowing contained 35.1% of bunted heads compared with 26.3% from seed sown 24 hours after treatment and at the ½-ounce rate there was 30.7 and 27.2% of infection, respectively, from delayed and immediate sowing.

EFFECT OF DELAYED SOWING ON BUNT INFECTION

In three of the four seasons (Table 1) bunt infection was low in both treated and untreated wheat sown the day the soil was inoculated, although moisture and temperature were favorable for moderately high infection. Bunt infections were much higher in the second sowings made 7 to 10 days later. They continued to be high in the later sowings, with some fluctuation, until 30 to 50 days had elapsed after the soil was inoculated. In wheat sown after this period the bunt infection was low in both treated and untreated rows.

In 1933-34, the first sowing was made November 3 and the last sowing on November 23 All plants emerged during the late winter. Bunt infection was uniformly high in the untreated wheat sown on all four dates, and that treated with New Improved Ceresan had 18 to 40% of bunted heads. At the time of the sowing on November 3 temperatures apparently were low enough to favor a high bunt infection Several weeks were required for the plants to emerge, but this may not have been a factor, as Faris (2) and Leukel (7) found a negative correlation between days from sowing to emergence and the percentage of bunt in the crop.

In 1931-32, there was a decided decrease in the percentage of bunt in the wheat sown 32 days after inoculation of the soil compared with that sown earlier The percentage decrease was even greater for the sowing made 40 days after inoculation. The proportion of the decrease resulting from loss of spore viability cannot be determined, however, as a part may be attributed to lower temperatures.

Percentages of infection fluctuated considerably in 1934-35, but the irregularities approximately followed deviations of temperature. During the period between October 3 and 14 the mean air temperature was high, ranging from 46° to 63° F, and wheat sown October 3 had a low bunt infection. A drop in infection not explainable by temperature was shown in the untreated check sown 42 days after soil inoculation, but this drop did not occur in the treated rows However, the sowing made 8 days later, or 50 days after soil inoculation, showed distinctly less infection. In this case, the temperature did not fall below 40° F for nearly 3 weeks after the wheat had been sown. Seed sown 7 days later on November 15 produced only 4.2% bunt in the untreated check.

In 1935-36, there was a sharp drop in infection in the sowing made 52 days following inoculation of the soil, and in the wheat sown 64 days after inoculation the infection dropped to 7 3% in the untreated check.

The seasonal trend in bunt infection in treated and untreated wheat was very similar. In 1931-32, there was only 15.7% bunt in the untreated check from the first sowing, but this increased to 73.3% in the second date, although moisture and temperature conditions remained about the same.

SUMMARY

The results of 4 years' experiments on the control of bunt (*Tilletia* spp.) in wheat sown in artificially infested soil are presented.

New Improved Ceresan was superior to the other standard seed disinfectants tested. When applied at 3 ounces per bushel it reduced infection 66.3 and 74.8%, based on infection in the untreated checks as 100%. A 3-ounce rate sometimes caused a marked reduction in stand. Bunt was reduced 47.5 and 52.3%, by ½-ounce and 1-ounce rates of application, respectively. There was no consistent loss in effectiveness when the seed was treated 3 weeks before sowing.

Ethyl mercury iodide was about equal to New Improved Ceresan when the grain was sown 24 hours after treating, but there was a distinct decline in effectiveness when 10 days elapsed between treating and sowing.

Copper carbonate and copper sulfate were equally effective in controlling infection by spores in the soil. Copper carbonate reduced bunt in the crop 22.3 to 31.5% in the 4 years.

Results in one year indicated that under certain conditions formaldehyde may be as effective as copper carbonate and copper sulfate, but in two other years formaldehyde reduced infection only 4.4 and 10.3%.

Percentages of bunt were significantly lower when the wheat was sown the day the soil was inoculated and watered than when sown a week or 10 days later.

Under the conditions of this experiment, between soil inoculation and sowing 50 to 60 days usually were required before sufficient spores were destroyed to eliminate danger from heavy infection. Low temperatures, however, occasionally prevented heavy infection. Low percentages of infection were obtained in untreated checks sown 60 days or more after the soil was inoculated with bunt spores. The seasonal trend in bunt infection in treated and untreated wheat was very similar.

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COMPARISON OF DIFFERENT METHODS OF INOCULATING OAT SEED WITH SMUT[1]

R. W. Leukel, T. R. Stanton, and Harland Stevens[2]

FREQUENT failure to obtain high percentages of smutted plants in oat varieties and crosses that are not immune from or even highly resistant to smut is one of the principal difficulties encountered in the study of seed treatments and physiological races of oat smuts and in the development of smut-resistant varieties. This applies particularly to studies in which the seed is sown outdoors, because soil conditions immediately after sowing may be highly unfavorable to smut infection or development. When plants are grown in the greenhouse, moisture and temperature conditions may be adjusted and controlled so as to be optimum for smut infection, and high percentages of smutted plants are more easily obtained.

A number of investigators have described experiments in which the hulls of the oats were removed before applying the smut spores in order to insure a high percentage of infection. There are several objections to this method of inoculating oats, the chief one being the time and labor involved in removing the hulls. Both Johnston (3)[3] and Tapke (7) found that removing the hulls from naturally inoculated seed greatly reduced the amount of smut resulting from this naturally acquired inoculum, especially under field conditions. Stanton, *et al.* (6) reported that removing the hulls caused also an appreciable reduction in the percentage of emergence and in the percentage of plants reaching maturity.

In recent experiments by Leukel (4) the use of the spore-suspension-vacuum method as described by Haaring (2) resulted in relatively high percentages of infection. This method of applying spores to the seed involves but little labor, the seed is not injured, and the spores are placed under the hulls where, according to Gage (1), they may germinate and bring about infection in a manner similar to that supposedly obtaining in naturally inoculated seed.

The experiments here described were conducted at Arlington Farm, Arlington, Va., and at the experiment station at Aberdeen, Idaho. They were designed chiefly to compare the infection results following the application of dry smut spores to hulled[4] seed with those following the application of spores by the spore-suspension-vacuum method to unhulled seed of a highly susceptible, a moderately susceptible, and, in one case, a resistant variety. Other methods of inoculation were included as checks. Because loose smut (*Ustilago avenae* (Pers.) Jensen) and covered smut (*U. levis* (Kell. and Sw.) Magn.) are similar in their life histories, no attempt was made in these experiments to distinguish between the two species.

[1]Cooperative investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Idaho Agricultural Experiment Station. Received for publication July 28, 1938.

[2]Associate Pathologist, Senior Agronomist, and Assistant Agronomist, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 881.

[4]By the term "hulled" seed is meant seed with the hulls removed, while "unhulled" seed refers to seed from which the hulls were not removed.

MATERIALS AND METHODS

Varieties used.—Iogold, moderately susceptible to smut, and Victory, extremely susceptible, were used throughout the experiments. In the first experiment the resistant variety Markton also was included.

Smut used.—In 1936 a collection of loose smut (*Ustilago avenae*) from Ames, Iowa, was used. In 1937 a mixture of loose and covered smuts was used. The smut material was sifted through a 60-mesh sieve and stored at 10° C. Germination tests in 2% dextrose solution were made to determine the viability of the spores before the smut was used for inoculation.

Methods of inoculation.—Three methods of inoculation were used. In using the dry-spore method, the hulled or unhulled seed was dusted with a relatively large quantity of dry spores and then sifted to remove the excess spore material. In using the spore-suspension method, 2 grams of smut spores were added to a liter of 2% dextrose solution and the mixture was thoroughly shaken to get the spores into suspension. From 200 to 300 grams of seed were immersed in this liter of liquid for 20 minutes, the vessel being shaken at intervals to keep the spores and seed in suspension. The liquid was then drained off and the seed was spread out to dry for several hours. It was then placed in a chamber at 18° to 20° C and a relative humidity of 80 to 90% for 20 hours after which it was aired and stored until sowing time.

The procedure followed in the vacuum method was identical with that described for the spore-suspension method except that the liquid with the seed immersed in it was subjected to about 30 inches of vacuum during the period of immersion.

Sowing.—At Aberdeen, Idaho, the seed was sown in the field in 5-foot rows at the rate of 20 seeds per row. At Arlington Farm the seed was sown 1½ inches deep in small metal boxes containing soil adjusted to a moisture content of 60% of its water-holding capacity. These boxes, placed in larger covered boxes containing moist blotters to prevent the soil from drying, were kept in a chamber at 20° C until the plants emerged. At this time they were removed to the greenhouse and kept there until the plants were large enough to be transplanted.

In the first experiment at Arlington Farm the seedlings were transplanted to the greenhouse bench and in the second they were transplanted to outdoor beds. The seedlings were spaced 2 inches apart in both experiments.

Recording smut data.—Smut infection was recorded on the basis of both number of plants and number of heads Only the percentages of plants infected are presented here. The percentages of smutted heads were generally somewhat lower than the corresponding percentages of smutted plants. Since plants having only a part of the heads infected were recorded as infected plants, one reason for this difference is apparent. Plants that failed to produce heads were not included in the tabulation.

EXPERIMENTAL RESULTS

In the first experiment (1936) at Aberdeen, Idaho, the resistant variety Markton showed no smutted panicles, regardless of the manner of inoculating the seed. The plants grown from inoculated hulled seed were, on the whole, less vigorous than those grown from unhulled seed similarly inoculated. It is unfortunate that smut-free hulled and unhulled seed were not included for comparison.

The results with Iogold and Victory are shown in Table 1. In five of the eight trials, dusting hulled seed with spores resulted in the

TABLE 1.—*Emergence, final stand, and smut infection in spring-sown oats grown from hulled and unhulled seed inoculated with smut spores and grown at Aberdeen, Idaho, and Arlington Farm, Va., 1936 and 1937.*

Year	Condition of seeds	Method of inoculation	Iogold: No. seeds planted	Iogold: Emergence %	Iogold: Final stand %	Iogold: Infection %	Victory: No. seeds planted	Victory: Emergence %	Victory: Final stand %	Victory: Infection %
		Aberdeen, Idaho (Planted and Grown in Field)								
1936	Unhulled	Dry spores	100	—	72	21.0	100	—	63	6.4
1936	Unhulled	Spore suspension	100	—	80	26.2	100	—	61	37.7
1936	Unhulled	Spore suspension (in vacuum)	100	—	79	39.2	100	—	67	64.1
1936	Hulled	Dry spores	100	—	59	61.0	100	—	74	89.1
1936	Hulled	Spore suspension	100	—	48	35.4	100	—	74	72.0
1936	Hulled	Spore suspension (in vacuum)	100	—	61	37.7	100	—	54	61.0
1937	Unhulled	Dry spores	300	—	35	8.5	300	—	47	29.3
1937	Unhulled	Spore suspension	300	—	38	8.8	300	—	45	48.5
1937	Unhulled	Spore suspension (in vacuum)	300	—	38	42.5	300	—	45	88.1
1937	Hulled	Dry spores	600	—	31	36.2	600	—	30	75.8
		Arlington, Va. (Planted and Grown Indoors)								
1936	Unhulled	None	100	92	88	0.0	100	68	67	0.0
1936	Unhulled	Dry spores	510	92	74	27.4	510	78	71	69.9
1936	Unhulled	Spore suspension	510	88	71	35.2	510	75	64	83.8
1936	Unhulled	Spore suspension (in vacuum)	510	76	46	64.2	510	67	38	91.3
1936	Hulled	None	100	66	44	0.0	100	72	64	0.0
1936	Hulled	Dry spores	510	11	5	66.7	510	18	18	94.5
1936	Hulled	Spore suspension	510	15	12	36.7	510	32	18	92.3
1936	Hulled	Spore suspension (in vacuum)	510	21	14	43.1	510	40	20	92.2
		Arlington, Va. (Planted Indoors, Matured in Outdoor Beds)								
1937	Unhulled	None	100	71	70	1.4	100	36	36	0.0
1937	Unhulled	Dry spores	400	84	83	52.7	400	60	56	82.1
1937	Unhulled	Spore suspension	400	76	74	54.5	400	45	43	91.8
1937	Unhulled	Spore suspension (in vacuum)	400	56	51	87.2	400	36	31	95.1
1937	Hulled	None	200	30	27	0.0	100	40	40	5.0
1937	Hulled	Dry spores	1,600	15	10	81.9	1,656	10	8	98.4

highest percentages of infected plants, the average percentages of infection for all trials being 61.5 and 89.5 for Iogold and Victory, respectively, compared with 58.3 and 84.7%, respectively, for the vacuum method of inoculation applied to unhulled seed. Inoculating the unhulled seed with dry spores resulted in a relatively lower percentage of infection in all cases. Hulling and smutting the seed, however, usually resulted in very poor stands. Only 16%[5] of all the hulled smutted seeds planted in the four experiments produced mature plants, while 44% of the unhulled vacuum-inoculated seeds produced plants that reached maturity. The corresponding figure for unhulled seed dusted with spores is 64% and that for unhulled seed inoculated with a spore-suspension without vacuum is 59%. It is evident therefore, that the severe infection brought about by forcing the smut spores under the hulls of the seed also may result in somewhat reduced stands, but the reduction is not so great as that resulting from hulling and smutting the seed.

It should be borne in mind that in the two experiments at Arlington Farm the soil conditions immediately after planting were nearly optimum for smut-spore germination and for infection of the seedlings (5); therefore, these results differ somewhat from those obtained in the field, especially in the marked reduction in emergence from the heavily smutted hulled seeds.

DISCUSSION

The relatively high percentages of smutted plants obtained as a result of using the spore-suspension-vacuum method for inoculating unhulled seeds, along with the ease and simplicity of this method as compared with the laboriousness of the hulling process, suggests it as a logical method for inoculating large numbers of seeds. Furthermore, since the seed inoculated by this method is not so severely injured as it is by hulling and applying dry spores, it produces a better stand and a population from which probably more reliable data can be secured in genetic studies.

SUMMARY

Studies on the relative merits of different methods of inoculating seed of oats with smut seem to show the following:

1. Immersing the seed in a smut-spore suspension under vacuum may result in infection percentages as high as those resulting from hulling the seed and dusting it with spores.
2. Inoculation by the latter method in addition to being extremely laborious may cause a severe reduction in emergence and stand, even in smut-resistant varieties.
3. The suspension-vacuum method offers a quick and effective way of inoculating large numbers of oat seeds with spores of loose or covered smut.

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[5]Weighted average.

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AGRONOMIC AFFAIRS

ANNUAL MEETING OF SOCIETY

THE thirty-first annual meeting of the American Society of Agronomy will be held in the Mayflower Hotel, Washington, D. C., Wednesday, Thursday, and Friday, November 16, 17, and 18.

ANNUAL MEETING OF SOIL SCIENCE SOCIETY OF AMERICA

THE annual meeting of the Soil Science Society of America will be held at the Mayflower Hotel, Washington, D. C., Wednesday, Thursday, and Friday, November 16, 17, and 18. Tentative programs have been arranged for three sectional sessions morning and afternoon of the first day, a joint session with the American Society of Agronomy on the morning of the second day, and two sectional sessions on the afternoon of the second and morning and afternoon of the third day. The dinner and business meeting of the Society is scheduled for the evening of November 16.

MEETING OF WESTERN BRANCH OF SOCIETY

THE Western Branch of the American Society of Agronomy held its twenty-second annual meeting at the University of Arizona at Tucson August 31 to September 2. The first two days were devoted to the presentation of formal papers and the third day to inspection trips to the Soil Conservation Service Nursery at Tucson, the U. S. Field Station at Sacaton, and the Salt River Valley Experiment Farm at Mesa. Attendance ranged from 28 to 45.

Officers for 1939 were elected as follows: For President, Dr. R. J. Evans, Utah Experiment Station, Logan, Utah; and for Secretary, Coit A. Suneson, Division of Cereal Crops and Diseases, Davis, Calif.

SECTIONAL PUBLICATION OF "BIOLOGICAL ABSTRACTS" DECIDED UPON

BEGINNING with 1939 it will be possible not only to subscribe to BIOLOGICAL ABSTRACTS as a whole but also to obtain separate sections of BIOLOGICAL ABSTRACTS at a reduction in cost as compared with the subscription price for the complete ABSTRACTS. At the same time the ABSTRACTS will retain its entity

by continuous pagination of the volume and a complete index. This index will be supplied to each subscriber, thus assuring full covering of the biological sciences.

Without repaging or other change, except in the cover, it is proposed to break up the ABSTRACTS into the following subject groups or parts for 1939:

I. General Biology, including general biology, biography-history, history, bibliography, evolution, cytology, genetics, biometry, and ecology. Price, $4.

II. Experimental Animal Biology, including animal physiology, nutrition, pharmacology, pathology, anatomy, embryology, and animal production. Price, $9.

III. Microbiology and Parasitology, including immunology, bacteriology, viruses, parasitology, protozoology, and helminthology. Price, $5.

IV. Plant Sciences, including phytopathology, plant physiology, plant anatomy, paleobotany, systematic botany, agronomy, horticulture, forestry, pharmacognosy, and pharmaceutical botany. Price, $6.

V. Animal Sciences, including paleozoology, parasitology, protozoology, helminthology, systematic zoology, and economic entomology. Price, $6.

The subscription price for the complete volume for 1939 will be $25 to individual subscribers and institutions alike. Based on the experience of the past year, prompt coverage in 1939 is anticipated with a lag of not more than two or three months and with the index appearing in the spring. In order to facilitate plans for 1939, subscription blanks will soon be distributed to members of societies constituting the Union as well as to libraries and institutions.

NEWS ITEMS

J. D. GUTHRIE, formerly County Agent of Goochland County, Virginia and who spent last year at Cornell University where he received his M.S. degree in agronomy has been employed as Assistant Extension Agronomist, Virginia Polytechnic Institute, Blacksburg, Va.

D. D. MASON, who received his M.S. degree in agronomy in June 1938, has been employed as Assistant Agronomist by the Virginia Agricultural Experiment Station and assigned to soil survey field work.

DR. J. R. TAYLOR, JR., formerly Associate Soil Chemist, Alabama Experiment Station, has been appointed Agronomist for the Virginia-Carolina Chemical Corporation, Richmond, Virginia.

A CHAPTER of the Society of Sigma Xi will be installed at the University of Florida, Friday, October 28.

ROY W. SIMONSON and ROBERT W. PEARSON have been appointed Assistant Professors in the Agronomy Department at Iowa State College. Dr. Simonson will be associated with the soil survey and land use program in Iowa and Dr. Pearson will undertake research and teaching in soil fertility.

Doctor T. L. Lyon, formerly head of the Department of Argonomy, Cornell University and a charter member and Historian of the American Society of Agronomy, died at his home in Ithaca October 7.

The death of Professor John B. Wentz of the Department of Farm Crops, Iowa State College, occurred the latter part of September.

Doctor C. R. Burnham, University of West Virginia, was appointed Associate Professor in the Division of Agronomy and Plant Genetics, University of Minnesota, beginning September 1.

Lewis C. Saboe, a graduate of South Dakota State College, has accepted a teaching assistantship in agronomy and plant genetics, University of Minnesota.

David Reid has resigned as Assistant in Agronomy and Plant Genetics, University of Minnesota, to become Agent in Wheat Investigations with headquarters at Amarillo, Texas.

Among the new graduate students in Agronomy and Plant Genetics, University of Minnesota, are I. M. Atkins, U. S. Dept. of Agriculture, Denton, Texas; D. C. Tingey, Utah Agricultural Experiment Station, Logan, Utah; L. L. Robertson, Dominion Department of Agriculture, Calgary, Alberta, Canada; Wm. Semeniuk, Howard B. Peto, and J. R. Weir, University of Alberta, Canada; and H. T. Yang and K. W. Wang from China.

ERRATUM

In the article on "Effectiveness of Spraying with Fertilizers for Control of Weeds on Arable Land" by B. N. Singh and K. Das, appearing on pages 465 to 474 of the current volume of the Journal the following corrections should be made: The first citation to literature on page 465 should be to a paper by B. N. Singh, K. Das, and G. V. Challam on "Effectiveness of Cultural Treatments in the Control of Weeds," Empire Jour. Exp. Agr., 5: 63–68. 1937. Also, in Table 3 on page 469 "*A. album*" should read "*A. arvensis*."

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MINOR ELEMENTS AND MAJOR SOIL PROBLEMS[1]

L. G. WILLIS AND J. R. PILAND[2]

RESEARCH in soil fertility has been based largely upon the principle of limiting factors which implies that crop production is governed by the supply of that essential element which is furnished in the least fraction of the amount required for maximum growth. It is further assumed that the functions of these elements are in a major degree independent and additive.

The need for supplying nitrogen, phosphorus, potassium, lime, and organic matter to soils has been recognized for over a century. Minor elements, such as boron, copper, magnesium, and manganese, have been more recently added to the list of supposedly essential elements. When a response to any of these minor elements has been demonstrated, it has been assumed that this constitutes proof of a specific deficiency and that it is only necessary to add a compound containing the respective element to an otherwise adequate fertilizer to produce satisfactory results.

Such concepts do not always conform to the evidence. Before pointing out some of the inconsistencies of current ideas, however, it is desirable to introduce a discussion of fundamental logic.

PRINCIPLES OF LOGIC

The successive steps in research as it is applied to soil fertility can be presented diagramatically as in Fig. 1. The initial undertaking is that of assembling original observations and data. These may be formal or informal, exactly quantitative or only approximately so. From them, by a process of induction, a theory is developed. Then, by deduction, a number of independent objective tests are devised, each designed to produce evidence by which the validity of the basal theory can be judged. It is not logical to use the data from which a theory is derived as supporting evidence. Ultimate proof of any conclusion may be impossible, but approximate proof is assumed when

[1]Paper read before Section O (Agriculture) of the American Association for the Advancement of Science, Indianapolis, Ind., Dec. 28, 1937. Published by permission of the Director of the North Carolina Agricultural Experiment Station as paper No. 104 of the Journal Series. Received for publication August 1, 1938.

[2]Soil Chemist and Assistant Soil Chemist, respectively.

no objective test fails to support the theory. A theory is acceptable as truth, therefore, only when it cannot be disproved. At any time, a single contradictory observation will necessitate some degree of modification.

The misuse of statistical methods of analysis of data frequently leads to erroneous conclusions. In an experiment to determine the potassium requirements (for example) of a crop on a soil of any given category, it is customary to determine the significance of the differences in yield of crops produced by various amounts and sources of

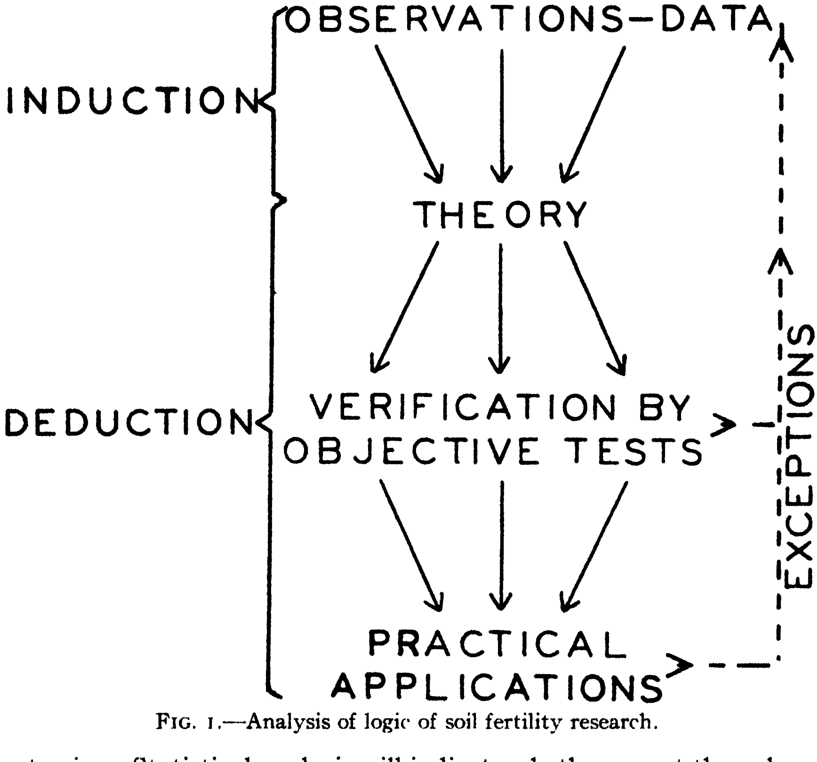

FIG. 1.—Analysis of logic of soil fertility research.

potassium. Statistical analysis will indicate whether or not the values determined are mathematically real. No detail of the calculation justifies the assumption that the results are significant in the sense that they are in any degree indicative of a specific response to potassium. If it should be shown that in a single instance a similar response could be produced by another treatment the effects of which are independent of potassium, it must be concluded that the interpretations implying a potassium deficiency have been incorrect. As the minor elements have been introduced into the program of work it has become increasingly evident that their effects are not independent of those of the common fertilizer materials. Results of experiments invariably measure the gross efficiency of fertilizer materials—not the effects of single elements nor of any particular function of these elements.

It should also be noted that all interpretations of research work are based upon assumptions or postulates which are not necessarily accurate. This generalization applies in particular to the rapid chemical tests for plant nutrients in the soil. The tests are standardized against interpretations of observations and as the latter are revised the standardizations will have to be altered accordingly. It is not improbable that the current difficulties found in developing these chemical tests are related more to the defects of basic concepts of soil fertility than to the limitations of chemical methods.

POTASSIUM "DEFICIENCY"

In the following discussion attempts will be made to illustrate only a few of the complexities of major soil problems which have been disclosed by experiments with the minor elements. For purposes of simplification, negative aspects will be emphasized. Results of specific objective tests, some of which have already been published, will be introduced to support the opinion that many of the classical ideas regarding the major principles of soil fertility are subject to question and that the functions of some of the minor elements are so intimately associated with major soil problems as to merit consideration in every detail of organization and interpretation of research work.

In the foregoing discussion reference was made to a suppositive experiment with potassium. An example has been published (3)[3] in which the data obtained on one field can be compared with that of another experiment (16) on adjacent plats. To facilitate the discussion the pertinent results are restated in Table 1. The basal fertilizer was identical in each experiment, except that in the work with copper and manganese a soluble source of magnesium was applied to all plats.

TABLE 1.—*Relative effects of potash, manganese, and copper on yield of cotton where "rust" is prevalent.*

Potash plats		Copper-manganese plats	
Treatment per acre	Lbs. seed cotton per acre	Treatment per acre	Lbs. seed cotton per acre
Fertilizer alone	965	Fertilizer alone*	1,320
Fertilizer with:		Fertilizer with:	
25 lbs. potash (sulfate)	1,205	5 lbs. manganese sulfate	2,040
25 lbs. potash (muriate)	1,385	10 lbs. copper sulfate	1,960
25 lbs. potash (kainit)	1,550		
25 lbs. potash (sulfate of potash-magnesia)	1,545		

*This formula was identical with that used on the potash plats except that it contained soluble magnesia.

Evidence of a response to magnesium was found in the potash experiment, but unfortunately magnesium was not supplied with the most efficient source of potassium. By any comparison of actual or

[3]Figures in parenthesis refer to "Literature Cited", p. 894.

calculated yields, however, it is obvious that small amounts of either copper or manganese produced results at least as satisfactory as were obtained with the additional amounts of potash fertilizers. The sponsors of the work with potash, having access to the results with copper or manganese, concluded that "factors other than potash may be involved". Those responsible for the work with copper and manganese have no positive opinion regarding the most practical remedy for cotton "rust". The general significance of these results lies in the fact that the potash experiment quite definitely "proved" the fact of a potassium deficiency. *The possibility of error was evident only after an experiment was designed to test an extremely doubtful theory.* If the minor element effect had been determined first the error might have been reversed.

FIG. 2.—Accumulation of manganese (1) in nodes of corn stalk; (2) normal corn stalk.

No extensive discussion of this phase of the soil fertility problem can be undertaken Hoffer (1) has shown that a condition remedied by potash fertilizers, which he identifies as a deficiency, is characterized by an accumulation of iron in the nodes of corn plants. Evidence from Ohio (8) indicates that the symptom is not infallible in either the positive or negative sense. Numerous semiquantitative tests have suggested the probability that symptoms generally considered indicative of potassium deficiency are in fact caused by an excessive intake of iron or manganese by the plants. Copper (12) or potassium salts (1) will control the former and apparently manganese is also effective. The visible symptoms caused by an excess of manganese (Fig.

2) are similar to those caused by iron, but it is probable that any soluble salt will, by a base exchange reaction (6), greatly increase the injury from manganese. (It may be stated at this time that experiments now in progress have demonstrated that manganęse cannot be made insoluble in some soils by liming even at rates to produce pH values of 7.5.)

Other evidence dealing with supposedly specific effects of potassium will be introduced under the discussion of the phosphorus problem.

PHOSPHORUS DEFICIENCY

For the sake of simplification all general references to the experimental work with phosphorus will imply that ordinary superphosphate is the source of the element. Considering all of the components of this material there are on record at least ten major physiological effects that can be attributed to superphosphate, only one of which is the direct physiological function of phosphorus.

The complexity of the phosphate problem can be conveniently illustrated by the results of a reconnaisance experiment on a muck soil. Past experience had indicated that a standard complete fertilizer was ineffective, but the normal interpretation of no nutrient deficiency was complicated by evidence that phosphates alone were injurious (1, 9). In earlier interpretations it had been inferred that this denoted an unfavorable nutrient ratio, but, since the injury was usually associated with an apparently excessive intake of iron, an opinion was reached that the problem involved some features of an oxidation-reduction equilibrium (16).

Direct experimental support for this opinion appeared to be unobtainable so it was assumed from fragmentary evidence that the sequence of reactions was as follows: An injury was caused by iron which was brought into solution by reduction promoted by microbial activity which was in turn stimulated by the phosphate. This implied that the decrease in yield with the phosphate was evidence of a deficiency of phosphorus in the soil for the higher as well as the lower orders of plants. If, therefore, the reductive influence could be controlled, phosphorus should be beneficial. Copper sulfate was applied to soils in the field on the further assumption that it would act favorably as a catalyst of oxidation.

The only data indicative of an actual response to phosphorus comes from an experimental field[4] where copper sulfate was added to one-half of each plat of an experiment originally designed to test the efficiency of various sources of phosphorus. Unfortunately *nitrogen* was included in some of the treatments making it impossible to state that the results were due solely to other materials.

There is an element of inconsistency in the foregoing reference to nitrogen. Actually, the material used was nitrate of soda. The possible significance of this distinction will be discussed later, but for convenience, reference will be made indiscriminately to the element although it is recognized that the material is perhaps the more significant designation.

[4]Unpublished results furnished by W. H. Rankin.

In Fig. 3 it is shown that the plat receiving nitrogen and phosphorus produced less yield than did the unfertilized soil but that either copper or potassium served as a remedy for this adverse condition. A more striking effect of copper was found with the complete fertilizer. Since copper did not produce a comparable increase in yield without fertilizer, it is evident that *there was a need for standard fertilizers on this soil which had not been demonstrated before the copper was added.* It is still impossible to state what part of the composite effect was caused by the individual ingredients although the theory on which the application of copper was based implies a serious deficiency of phosphorus and no specific deficiency of copper as a plant nutrient.

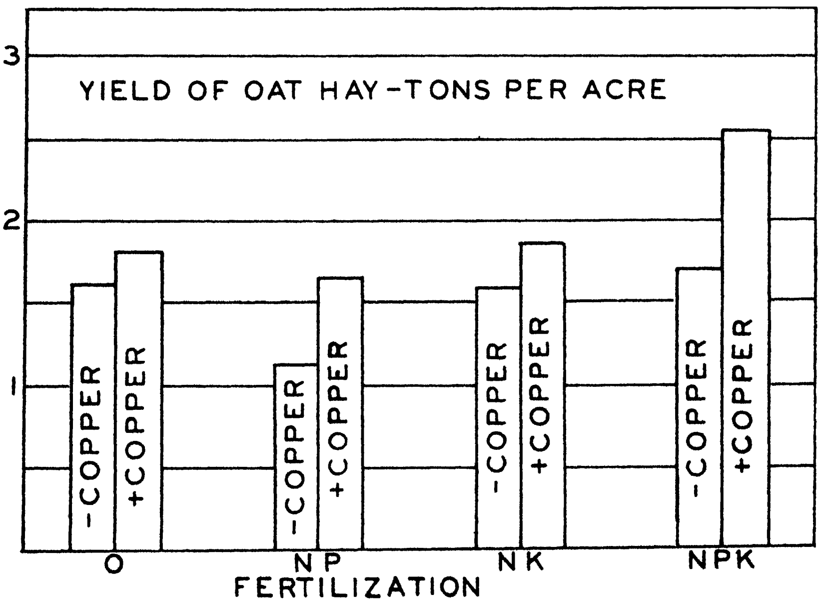

FIG. 3.—Influence of fertilizer and copper sulfate on yield of oats on a muck soil.

Recent observations indicating a widespread need for boron seem also to have a bearing on the phosphate problem. Evidence that calcium compounds increase the apparent deficiency of boron suggests that the efficiency of superphosphate may be seriously impaired where the boron supply of the soil is low. Under such conditions, orthodox methods of experimentation would lead to erroneous conclusions.

It is also evident, in view of the known effect of calcium sulfate as a solvent for both potassium and magnesium in the soil (11), that the results obtained with phosphate may be governed in part by this function. Any fertilizer mixture containing superphosphate which may be designed for use on soils at the threshold of either potassium or magnesium deficiency may therefore give false values attributable to phosphorus. Conversely, the deficiencies of potassium and magnesium evidenced where high analysis fertilizers have been used may be indicative of limited solvent action rather than to lesser amounts

of these elements in the fertilizer. This detail of the fertilizer problem leads to a suggestion that an apparent superiority of superphosphate over other sources of phosphorus may be indicative of a soil-depleting effect with the former material.

NITROGEN

A distinction between the use of the term nitrogen and nitrate of soda has already been drawn. In addition to the recognized effects upon soil reaction, the possibility of the intervention of oxidation-reduction phenomena must be considered. So, for example, the results of experiments with oats on the muck soils do not indicate a need for nitrogen any more than for oxidation. The relative efficiency of ammonium and nitrate nitrogen may in many instances depend upon the latter factor. Since it appears that copper will promote oxidation, it would be expected that this element might under some conditions modify the efficiency of ammonium nitrogen, or, equating other effects to that of copper, it might be expected that the exclusive use of ammonium nitrogen would increase an apparent rather than a real requirement for potassium.

As regards the functions of organic forms of nitrogen, evidence of a fallacy in the conclusion that these are valuable because of their slow availability has already been published (5). From the information available it appears that the organic ammoniates in general derive their efficiency in an appreciable degree from an effect common to all forms of readily decomposable organic matter and that differences in efficiency of the various sources of organic nitrogen may be attributable in part to functions of the minor element impurities.

SOIL ACIDITY—LIME

Extensive areas of soil in the southeastern states have not responded to liming as have soils in other parts of the country. Results of field experiments have proved that liberal liming has not been beneficial and this in turn has led to a conclusion that the soils must be kept distinctly acid For some time it has been known that liming will promote a deficiency of manganese (10) on many of these soils and more recently it has been found that boron will apparently correct some of the adverse effects of liming (14, 4). The further observation that manganese deficiency symptoms have been nearly eliminated by an application of borax (15), together with an unrecorded observation that heavy fertilization increases the severity of manganese deficiency, suggest a wide field for further research.

It is obvious, however, that few of the conclusions derived from liming experiments are dependable where deficiencies of boron or manganese are potential limiting factors in crop production. In this, as in other similar problems, the burden of proof rests with the experimental work to show that these factors are not involved. It is not improbable that in the avoidance of certain minor element deficiencies, many soils have been maintained at pH values so low as to impair their productiveness.

The influence of calcitic and dolomitic limestones relative to magnesium deficiency is already recognized and experimental procedures have generally been revised to correct some of the errors of prior work.

MOISTURE RELATIONSHIPS

A chance observation (15) supported by a number of unrecorded experiences indicates that an abnormal susceptibility of plants to wilting may be controlled by applications of borax to the soil. The conditions have been such as to make it seem improbable that the results were due to appreciable differences in the supply of available moisture. Further research will be necessary before extensive comment can be justified relative to this feature of the work.

ORGANIC MATTER

The beneficial functions of organic matter in soils have been ascribed to improvement in physical condition, better moisture retention, and promotion of microbial activity. The latter effect is more or less vaguely associated with increasing the availability of plant nutrients. Any or all of these functions may be significant, but it is of more than casual interest that in Florida manure has corrected a manganese deficiency (7), in Finland manure has produced a response similar to that of boron (2), and that in North Carolina manure has corrected a condition indicative of a potassium deficiency (9) which was later found to be controllable by copper sulfate. In a direct comparison by means of pot culture studies (15) a very light application of a mixture of copper and manganese has produced results with tomatoes comparable to those obtained with 5 tons of manure.

Before this information had been obtained, comprehensive systems of farming had been developed with the application of animal manure as an essential part of the program. The possibility that a considerable part of the value of the manure is derived from some minor ingredient has not been seriously considered—except where the use of manure has become impractical.

GENERAL DISCUSSION

The foregoing evidence may seem insufficient to justify serious consideration. The philosophical principle, however, provides that although a mass of data may support an opinion, a single observation can refute it. Great emphasis has been placed upon *facts* and *fundamental data* in research. Facts and data are matters of record and are valuable only as they can be projected by means of theoretical interpretations into untested usages.

Interpretations are fallible. According to a critical analysis of the basal assumptions regarding soil fertility, it seems that the only one which can be accepted without question is that plants require certain mineral elements for normal development independently of their environment. A few other details of the soil fertility problem may also be considered sufficiently well established to serve as a basis for further work.

To a great extent, however, current experimentation is based upon empiricisms and fallacies. It is often implied that if crude materials are used in sufficient amounts to supply the major nutrient elements, the minor element requirement will usually be satisfied. The only criterion of the adequacy of the supply of any element is plant response. In the absence of other identifying symptoms it would be impossible to state whether the limiting factors were the major or the minor components of any material. It is not improbable that the apparent requirements for major elements, as determined by ordinary field experiments, are in many cases distorted because, on the one hand, the yields are dependent upon some minor constituent of the fertilizer, while on the other, the requirements of the minor elements may be governed by some unidentified constituent of the fertilizer.

In view of all of these dependent factors it appears impossible to design an experiment that will produce accurate evidence of the amounts of nutrient elements necessary to produce a maximum crop in a soil even with the use of highly purified materials. Data purporting to indicate the "availability" of major or minor nutrient elements is also subject to misinterpretation. It would be interesting, for example, to determine whether or not the "availability" of the phosphorus in basic slag is in any degree dependent upon the influence of manganese or any other secondary constituent. A chemical method of analysis has been based on the assumption that the efficiency of the material is the measure of the availability of the phosphorus.

Acceptance of the foregoing opinions would appear to eliminate the field plat fertilizer experiment from a research program. This, however, is not a rational interpretation. It is only necessary to put the fertilizer experiment into its logical position as an objective test of a theory or as a detail of the practical application of research. If the latter is developed by deduction from approximately sound principles, it is a legitimate phase of a research program. When this perspective is introduced no difficulty will be experienced in converting the results of so-called fundamental research into practice. Comprehensive field experiments designed to determine empirical or independent values for fertilizer and lime requirements, and deficiencies or availabilities of nutrient elements are of questionable scientific or practical value even though every provision be made to insure technical accuracy.

As the complexities of soil fertility problems become more evident it may be well to consider whether or not the practical interpretations of research can be expressed in simple language so that farmers can be guided by printed directions. This was possible so long as land could be divided into that which would respond to normal fertilization and that which was unsuitable for cultivation. With the introduction of the minor elements as correctives of causes of unproductiveness, however, simple directions are no longer satisfactory. It may appear that where the limitation applies, soils are abnormal and limited in area. It is impossible, however, to identify the abnormal without defining the normal and a fair appraisal of recent developments points to the conclusion that the minor element problem involves in some

degree many soils, perhaps a majority, that have been hitherto considered normal.

The perspective introduced into soil fertility experimentation by research on the functions of the so-called minor elements directs attention to the defects in the interpretations of prior work. The scientific objective of modifying single independent variables is demonstrated to be unattainable in fact even though it has been made the basis of all fertilizer experiments. The interpretations of such experiments are therefore subject to unavoidable errors and practical applications derived from them are in some degree empirical. Recognition of this fundamental limitation constitutes the first step in increasing the efficiency of fertilizer usage. Further progress must depend upon accidental discovery or upon a more rational development of experimental procedure.

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GROWTH AND YIELD IN WHEAT, OATS, FLAX, AND CORN AS RELATED TO ENVIRONMENT[1]

R. S. DUNHAM[2]

THE complex of factors included in environment importantly affects the growth and yield of plants. As Klages (4)[3] has suggested, the plotting of growth curves should add a datum to those observations commonly recorded by agronomists that would aid in the interpretation of varietal yields. There may be further uses for growth curves in determining the relative importance of certain environmental factors in one region as compared to another and even in estimating crop yields in an area of similar climatic conditions. The concensus of those who have attempted correlation of weather with yield and forecasts of crop production on the basis of meteorological data is that more refined studies are necessary in order to determine the possibility of forecasting yields in any given region.

The studies reported in this paper, made during 1934 to 1937, inclusive, include height measurements and phenological data for wheat, oats, flax, and corn in relation to temperature, precipitation, and moisture content of the soil under the growing crop.

REVIEW OF LITERATURE

The literature on the correlation of weather and crop yields with the view of forecasting such yields is much too voluminous to review in detail. Summary of this literature until 1929 has been published by the Food Research Institute, Stanford University (5), and an unpublished abstract of foreign investigations has been made available to the writer by the Bureau of Agricultural Economics, U. S. Dept. of Agriculture. A list of selected references on weather-crops compiled in the Department of Agronomy and Economics and Sociology, Kansas State College, Manhattan, Kansas, has been distributed in mimeograph form. Investigators are generally agreed that most data now available are inadequate for deductions concerning the influence of factors of environment on crop growth and yield. Although some forms of meteorological data are quite complete, phenological data are not. Furthermore, phenological observations at closer intervals than are commonly made appear desirable and perhaps essential. There is a need for basic knowledge concerning the influence of weather factors on plant growth.

Chilcott (3), in a summary of investigations covering 218 crop years at 16 stations on the northern Great Plains, found that, "Notwithstanding the fact that annual precipitation is a vital factor in determining crop yield, it is seldom if ever the dominant factor; but the limitation of crop yield is most frequently due to the operation of one or of several inhibiting factors other than shortage of rainfall."

Oldsberg and Griffing (5) call attention to two critical periods in the life of the

[1]Contribution from the Northwest Experiment Station, Crookston, Minn. Paper No. 1621 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication June 9, 1938.

[2]Agronomist and Assistant Professor. Critical reading of this paper by Dr. F. J. Alway, Chief of the Division of Soils, and Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, is gratefully acknowledged.

[3]Figures in parenthesis refer to "Literature Cited", p. 908.

wheat plant, *viz.* (a) germination and formation of the first leaf and (b) flowering. Since the size of the first leaf determines the size of the second leaf and the size of the second leaf influences the size of the third leaf, ultimately the size of the first leaf influences importantly the size of the plant. During the period from the formation of the first leaf to heading, the plant is far less sensitive to weather than during germination and emergence unless weather conditions are extreme. The amount of soil moisture in the period just prior to heading is very important.

Van deSande-Bakhuyzen and Alsberg (8) believe that, "the loss of water is the most important phenomenon occurring at the time of flowering. It is the initial phase of death of the annual." The length of survival (5) after flowering is an important factor determining yields. Any environment conducive to drying hastens death and consequently reduces yields.

Pope (6) found that, "total height . . . indicates fairly well the growth stage of a plant. As a measure of growth it is, however, subject to certain sources of error. . . . Each leaf has its own grand period of growth and therefore the grand period of growth, as indicated by the curve of the height of the plant, varies with the growing activity of the leaf extending the greatest distance distally from the crown. . . . This error is greatly reduced by averaging the measurements of a plant population which varies in number and stage of growing leaves."

MATERIALS AND EXPERIMENTAL PROCEDURE

The surface soil of the plats used in this investigation is black silty clay loam underlaid with a calcareous lacustral clay. The texture of the soil and subsoil is indicated by the moisture equivalents reported in Table 1, which were determined by the Division of Soils of the University of Minnesota.

TABLE 1.— *Moisture equivalents of samples of soil from different plats.*

Depth, inches	Moisture equivalents						Average wilting coefficient*
	Plat 1	Plat 2	Plat 3	Plat 4	Plat 5	Average	
3- 6	24.9	24.7	24.9	24.5	25.1	24.8	13.5
9-12..	23.2	22.1	20.3	22.6	21.1	21.9	11.9
21-24..	25.6	25.6	23.4	20.4	25.2	24.0	13.0
33-36	27.8	28.1	28.5	24.5	28.3	27.4	14.9

*Wilting coefficient-moisture equivalent multiplied by $\frac{1}{1.84}$. (Briggs, L. J., and Schantz, H L. Wilting coefficient for different plants and its indirect determination. Bur of Plant Ind., U. S. D A Bul. 230. 1912)

The soil of these plats does not respond to applications of nitrogen or potassium fertilizers. Liberal amounts of treble superphosphate were applied broadcast in 1934 and placed with the seed in 1937 so it may be assumed that growth and yield were not limited by a deficiency in soil nutrients. The plats were all kept in bare fallow the year before the investigations began and have been cropped subsequently, as shown in Table 2.

Varieties used were Thatcher wheat, Anthony oats, Redwing flax in 1934 and 1935 and Bison in 1936 and 1937, Northwestern Dent (Crookston) corn, and the common biennial white sweet clover.

The purpose of the study was to compare the growth curves and yields of wheat, oats, flax, and corn over a period of years in relation to environmental conditions. A fortieth acre plat of each crop was sown and 10 plants selected from each plat. Soon after emergence these plants were tagged and measuring bases placed be-

TABLE 2.—*Crop sequence on plats.*

Plat No.	1934	1935	1936	1937
1	Wheat	Sweet clover alone	Sweet clover	Wheat
2	Oats	Wheat	Corn	Oats
3	Barley	Oats	Corn	Flax
4	Flax	Flax	Flax, sweet clover	Sweet clover
5	Wheat, sweet clover	Sweet clover	Flax	Corn
6	Sweet clover sown alone	Sweet clover	Oats	Corn
7	Corn	Corn	Wheat	Corn

side each. The bases consisted of a piece of heavy wire about a foot long with a 1-inch piece at the top bent at right angles. The wire was then inserted in the ground until the bent over top lay horizontal on the surface. During the season these measuring bases were covered several times with soil that had washed or blown over them, but they were easily uncovered. They provided a base from which all measurements were made and which eliminated errors that would have followed the use of the ground surface for this purpose.

Heights in inches were taken at approximately weekly intervals from the measuring base to the tip of the tallest leaf or the tip of the inflorescence, whichever was taller. In averaging the height of 10 plants, the error due to measuring the same leaf which varies in its growth activity was reduced. (6). Furthermore, the method of measuring length-growth removed the obvious objections to determining mass whereby samples would of necessity be removed from the field and new samples required for each determination.

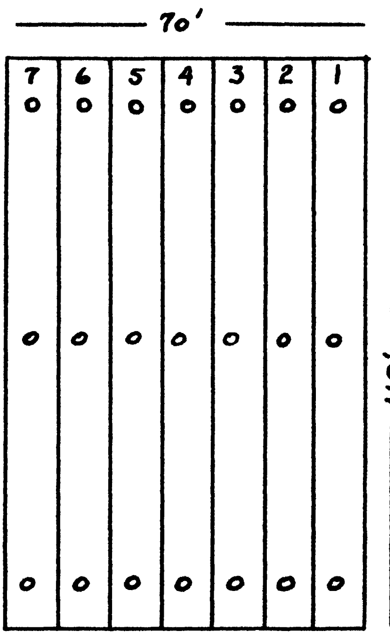

FIG. 1.—Arrangement and dimensions of plats showing approximate location of borings for soil moisture samples.

Soil moisture samples were taken at 3- to 6-inch, 9- to 12-inch, 21- to 24-inch, and 33- to 36-inch depths at intervals of approximately 2 weeks. Borings were made at three locations on each plat (Fig. 1), the soil thoroughly mixed, and a composite sample used for the determination. The percentage of total moisture was found by drying the samples in an electric oven at 100° C.

For the first three years, 2 square yards were cut from each plat at time of each height measurement, the plant material dried to a water-free basis, and weighed. However, the lack of uniformity in stand and growth made comparisons of one cutting with another of doubtful value, so this procedure was discontinued.

Two square yards per plat of wheat, oats, and flax were cut for yield but weight of 1,000 seeds was based on seeds from the 10 plants on which observations were made. In corn, a measured portion of the row was harvested. The area used was too small for reliable comparisons of the grain so only yields of stover are reported.

RESULTS

In Fig. 2, growth curves for wheat, oats, flax, and corn for each of the four seasons are shown. The curves connect points which represent the average height of the 10 individuals measured at approximately weekly intervals except where the data from an individual have been discarded for reasons discussed below.

The use of several individuals for measurement has several advantages over mass sampling, as follows: (a) A comparison of individuals may be made in growth, yield, and disease. A factor obscured in measurements of mass samples may easily be disclosed in the observation of individuals. Thus, wheat plant No. 4 in 1934 bore 39 kernels per spike as compared to 28.9, the average for the other nine individuals. Its kernels weighed 34.5 grams per 1,000 as compared to the average of 26.3 grams. It carried 10% stem rust as compared to a maximum of 2% for the other individuals. After heading, this individual proved to be a rogue and all data pertaining to it were discarded. (b) Individuals accidentally injured or killed are easily detected and eliminated from consideration. In 1936, oats plant No. 8 was injured. In four successive measurements it fell short of the average height by 2.6 inches, 4.8 inches, 6.2 inches, and 10.6 inches. (c) Variation due to individual differences may be measured and used for the determination of this error. (d) Individuals may be selected in areas of full stand and free from weeds, ant hills, animal droppings, etc.

In Table 3, precipitation data for the four years are presented. A comparison of the cumulative precipitation for these years with the average for 36 years shows that (a) the precipitation is average for 1934 if the excess moisture from the preceding season is disregarded and since this excess did not appear in soil moisture samples taken in the early spring (Table 4), it may be disregarded; (b) the precipitation for 1935 is also approximately average; (c) the precipitation for 1936 is below average all season; and (d) the precipitation for 1937 is generally above average.

The moisture stored in the soil from the end of one crop year till the beginning of the next is a factor to be considered. A column in Table 3 reports "Precipitation since harvest last year". Since the land on which the plats were laid out was fallowed in 1933, the rainfall of the 1933 crop season is added to the precipitation of fall and winter in this year. No measurements of evaporation or run-off were made, but the soil on each plat was sampled at time of crop emergence and the percentage of water found. The percentages of total water in the soil under each of the four crops and average wilting coefficients at depths of 3 to 6 inches, 9 to 12 inches, 21 to 24 inches, and 33 to 36 inches for 1934–37 are given in Table 4 and presented graphically in Fig. 3.

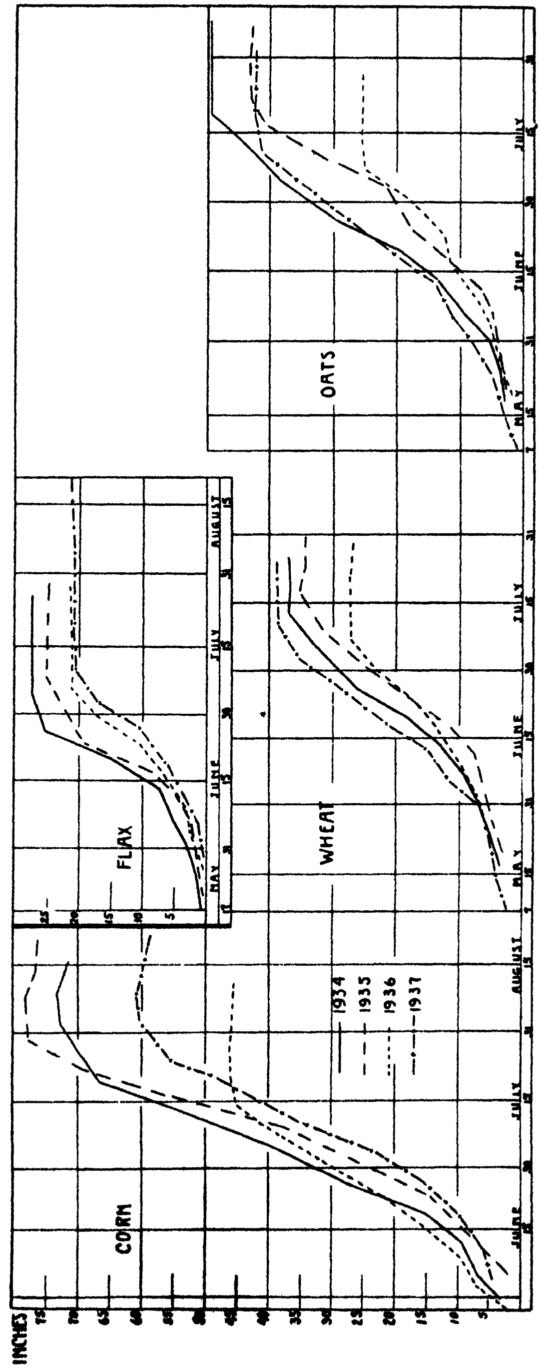

FIG. 2.—Growth curves for corn, flax, wheat, and oats during the seasons 1934–37. The ordinate represents height in inches and the abscissa, approximate date of measuring.

TABLE 3.—*Precipitation preceding and during the growing seasons 1934–37 and 36-year averages.*

Year and crop	Precipitation since harvest last year, inches		Cumulative precipitation during growing season															
1934			May 17	May 24	May 31	June 6	June 13	June 20	June 26	July 5	July 13	July 19	July 25	Aug. 1	Aug. 8	Aug. 16		
Wheat	May 1, 1933–May 7, 1934.	17.64	17.7	17.8	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	—	—	—		
Oats	May 1, 1933–May 7, 1934,	17.64	17.7	17.8	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	26.5	26.7	—		
Flax	May 1, 1933–May 7, 1934,	17.64	17.7	17.8	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	—	—	—		
Corn	May 1, 1933–May 22, 1934,	17.80	—	—	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	26.5	26.7	27.2		
36-yr. av.	Sept. 1–May 17,	9.6	9.6	—	11.1*	—	—	—	14.4†		—	—	—	17.3‡	—	18.6§		
1935			May 20	May 27	June 6	June 11	June 17	June 24	July 2	July 9	July 16	July 22	July 29	Aug. 7	Aug. 13	Aug. 20		
Wheat	Aug. 8, 1934–May 4, 1935,	9.21	10.1	10.4	11.6	11.7	12.5	12.7	13.3	15.3	16.7	16.9	17.8	—	—	—		
Oats	Aug. 1, 1934–May 4, 1935,	9.27	10.2	10.5	11.7	11.8	12.6	12.8	13.4	15.4	16.8	17.0	17.9	18.3	—	—		
Flax	Aug. 8, 1934–May 14, 1935,	10.13	10.1	10.4	11.6	11.7	12.5	12.7	13.3	15.3	16.7	16.9	17.8	—	—	—		
Corn	Aug. 30, 1934–May 17, 1935,	9.22	—	—	10.7	10.8	11.5	11.8	12.4	14.4	15.8	15.9	16.9	17.3	17.6	19.9		
36-yr. av.	Sept. 1–May 20,	9.8	9.8	—	11.3*	—	—	—	14.6†	—	—	—		17.5‡		18.8§		
1936			May 19	May 26	June 3	June 9	June 16	June 23	June 30	July 7	July 14	July 21	July 28	Aug. 11				
Wheat	Aug. 7, 1935–May 6, 1936,	9.09	9.1	10.0	10.0	10.8	10.9	10.9	11.7	11.8	11.9	12.3	12.3	—	—	—		
Oats	Aug. 7, 1935–May 13, 1936,	9.09	9.1	10.0	10.0	10.8	10.9	10.9	11.7	11.8	11.9	12.3	12.3	—	—	—		
Flax	Aug. 7, 1935–May 13, 1936,	9.09	—	10.0	10.0	10.8	10.9	10.9	11.7	11.8	11.9	12.3	12.3	—	—	—		
Corn	Aug. 28, 1935–May 13, 1936,	5.91	—	—	6.8	7.6	7.7	7.8	8.6	8.7	8.7	9.1	9.1	9.2	—	—		
36-yr. av.	Sept. 1–May 19,	9.7	9.7	—	11.2*	—	—	—	14.5†	—	—	—		17.4‡		18.7§		
1937			May 7	May 15	May 23	May 29	June 5	June 12	June 19	June 26	July 3	July 10	July 20	July 24	Aug. 2	Aug. 7	Aug. 14	Aug. 21
Wheat	July 28, 1936–April 17, 1937,	6.01	9.3	9.6	10.8	11.0	13.9	14.3	14.5	14.8	14.9	15.1	17.8	18.6	20.2	—	—	—
Oats	July 28, 1936–April 19, 1937,	6.01	9.3	9.6	10.8	11.0	13.9	14.3	14.5	14.8	14.9	15.1	17.8	18.6	20.2	20.2	—	—
Flax	July 28, 1936–May 11, 1937,	9.51	—	—	—	11.0	13.9	14.3	14.5	14.8	14.9	15.1	17.8	18.6	20.2	20.2	20.5	20.6
Corn	Aug. 11, 1936–May 14, 1937,	9.44	—	—	—	—	13.6	14.0	14.2	14.6	14.6	14.8	17.5	18.3	19.9	19.9	20.2	20.3
36-yr. av.	Sept. 1–May 7,	9.0	9.0	—	—	—	11.1*	—	—	14.4†		—	—	17.3‡		—	18.6§	

*June 1. †July 1. ‡Aug. 1. §Aug. 15.

Although records of precipitation, run-off, evaporation, humidity, wind velocity, and temperature might disclose important relationships, it appears that the determination of soil moisture provides a single factor which represents a resultant of these elements of environment. Used over a considerable area in an effort to forecast crop yields, soil moisture data would tend to reduce the error intro-

TABLE 4.—*Percentages of total water in the soil under wheat, oats, flax, and corn and average wilting coefficients at depths of 3 to 6 inches, 9 to 12 inches, 21 to 24 inches, and 33 to 36 inches for each of the seasons 1934-37.*

Crop	Depth, inches	May 1934				June 1934		July 1934		Aug. 1934		Sept. 5, 1934
		8	16	23	31	8	21	6	20	1	18	
Wheat	3-6	25.1	25.8	24.1	23.3	29.3	22.0	21.9	19.7	12.0	—	—
	9-12	23.2	20.7	19.6	17.8	25.3	19.5	15.0	16.1	13.9	—	—
	21-24	20.7	21.0	20.3	19.7	23.7	18.7	16.6	15.7	16.4	—	—
	33-36	21.7	22.6	22.5	22.4	24.2	22.4	20.9	17.7	18.9	—	—
Oats	3-6	26.1	24.7	25.2	24.6	29.1	22.1	22.7	15.3	10.6	10.7	—
	9-12	21.1	18.9	18.1	18.3	20.5	17.5	13.5	13.1	7.5	8.6	—
	21-24	19.1	20.0	21.4	19.7	19.9	18.0	14.9	12.9	14.0	11.4	—
	33-36	20.2	22.0	20.6	21.1	22.1	21.0	22.1	18.8	16.9	13.1	—
Flax	3-6	25.8	26.0	25.2	23.7	29.5	20.2	19.0	15.0	9.7	—	—
	9-12	21.1	20.4	20.2	18.3	22.2	20.1	15.5	14.0	10.4	—	—
	21-24	17.9	16.4	15.9	17.6	21.1	17.1	16.6	9.5	8.7	—	—
	33-36	19.9	21.0	19.6	19.1	23.7	17.4	18.7	20.6	13.6	—	—
Corn	3-6	—	—	25.7	25.8	29.7	27.3	28.0	19.8	16.6	14.1	13.8
	9-12		—	19.9	19.1	22.3	22.8	21.7	18.8	9.9	8.0	9.3
	21-24	—	—	19.8	18.4	20.4	18.9	19.4	18.6	17.3	10.6	12.6
	33-36	—	—	21.4	22.1	21.8	21.7	21.6	21.3	21.6	17.9	15.2
		May 1935				June 1935		July 1935		Aug. 1935		
		10	24			6	20	5	19	2	17	
Wheat	3-6	24.8	24.5	—	—	26.5	22.9	26.1	19.5	17.2	—	—
	9-12	22.1	20.5	—	—	20.5	19.6	17.5	14.8	12.9	—	—
	21-24	20.2	20.7	—	—	20.5	18.5	17.1	18.2	13.8	—	—
	33-36	21.1	21.7	—	—	20.9	20.7	21.0	20.7	18.4	—	—
Oats	3-6	25.8	25.9	—	—	26.1	22.5	24.3	22.2	18.1	—	—
	9-12	19.7	19.7	—	—	19.8	19.3	15.1	13.9	8.5	—	—
	21-24	21.3	20.5	—	—	20.8	18.7	16.6	18.2	14.8	—	—
	33-36	22.1	22.5	—	—	21.3	21.2	19.6	22.1	20.2	—	—
Flax	3-6	—	26.4	—	—	28.1	24.9	28.1	21.3	18.7	23.6	—
	9-12	—	20.4	—	—	19.3	22.6	21.1	16.2	12.2	10.1	—
	21-24	—	18.4	—	—	17.0	16.7	20.6	16.9	13.2	11.5	—
	33-36	—	20.9	—	—	22.2	22.5	22.7	19.6	20.2	19.4	—
Corn	3-6	—	25.3	—	—	27.9	26.7	29.3	25.2	20.8	24.4	—
	9-12	—	18.1	—	—	19.5	20.2	20.6	18.2	14.1	11.9	—
	21-24	—	19.7	—	—	20.3	21.3	21.3	19.5	19.4	15.8	—
	33-36	—	20.1	—	—	21.0	21.5	21.7	21.8	21.4	19.5	—

TABLE 4.—*Concluded.*

Crop	Depth, inches	May 1936		June 1936		July 1936		Aug. 1936		
		16	29	12	26	10	24	2	14	31
Wheat	3-6	26.4	26.1	21.0	12.7	11.1	10.2	—	—	—
	9-12	19.5	22.0	15.3	9.5	9.0	6.6	—	—	—
	21-24	18.9	17.0	16.8	14.5	11.6	8.8	—	—	—
	33-36	21.1	19.8	18.2	15.4	14.2	9.6	—	—	—
Oats	3-6	25.8	26.3	23.1	26.7	13.2	9.0	—	—	—
	9-12	20.7	19.6	17.6	11.8	9.2	9.8	—	—	—
	21-24	18.5	19.7	18.7	16.6	13.3	9.6	—	—	—
	33-36	20.1	20.8	21.1	19.6	17.4	11.2	—	—	—
Flax	3-6	27.5	26.3	26.0	14.9	11.3	10.1	—	—	—
	9-12	20.0	18.2	19.2	11.8	8.4	8.3	—	—	—
	21-24	21.4	21.0	21.2	19.8	14.4	9.6	—	—	—
	33-36	20.9	21.5	21.2	21.6	19.5	14.0	—	—	—
Corn	3-6	27.7	27.8	24.0	25.3	16.9	27.0	—	—	—
	9-12	24.3	21.1	16.3	16.0	14.5	12.6	—	—	—
	21-24	23.2	22.8	21.1	23.6	20.3	17.9	—	—	—
	33-36	10.8	23.1	22.8	28.6	23.1	20.5	—	—	—
		May 1937		June 1937		July 1937				
		8	22	5	19	3	20			
Wheat	3-6	24.8	26.6	23.4	18.5	13.2	25.3	24.6	—	—
	9-12	21.4	24.4	22.3	17.4	14.8	21.4	17.6	—	—
	21-24	23.4	24.3	23.9	20.2	18.1	16.2	15.6	—	—
	33-36	22.1	22.4	23.3	24.8	18.0	14.1	13.7	—	—
Oats	3-6	26.6	26.6	26.8	21.9	13.3	24.0	23.7	—	—
	9-12	19.9	20.7	21.5	16.6	9.5	20.0	15.5	—	—
	21-24	22.4	23.7	22.9	18.7	18.6	13.0	14.0	—	—
	33-36	23.9	23.2	24.3	21.3	21.3	15.8	19.3	—	—
Flax	3-6	—	26.7	26.6	22.9	14.7	23.7	17.7	13.9	—
	9-12	—	19.2	20.0	18.0	14.4	18.7	13.5	11.6	—
	21-24	—	19.3	22.6	21.5	15.8	14.1	13.5	11.6	—
	33-36	—	20.9	23.0	23.9	21.1	17.2	16.7	13.4	—
Corn	3-6	—	27.1	26.5	25.3	23.5	26.1	22.1	18.9	15.7
	9-12	—	24.4	24.6	21.8	16.1	19.6	17.1	15.0	9.8
	21-24	—	23.1	23.5	20.7	20.3	21.5	19.7	17.7	12.3
	33-36	—	22.1	23.4	23.2	21.8	23.4	21.7	19.6	19.8

Average wilting coefficients

	3-6	13.5
	9-12	11.9
	21-24	13.0
	33-36	14.9

duced into crop condition estimates by local showers or local dry spots where no precipitation records are kept.

It is evident from Table 3, although difficult to explain, that there was no greater accumulation of water in the soil to a depth of 3 feet following fallow than in other years not preceded by fallow. In these years the precipitation from the harvest of the crop on each plat until

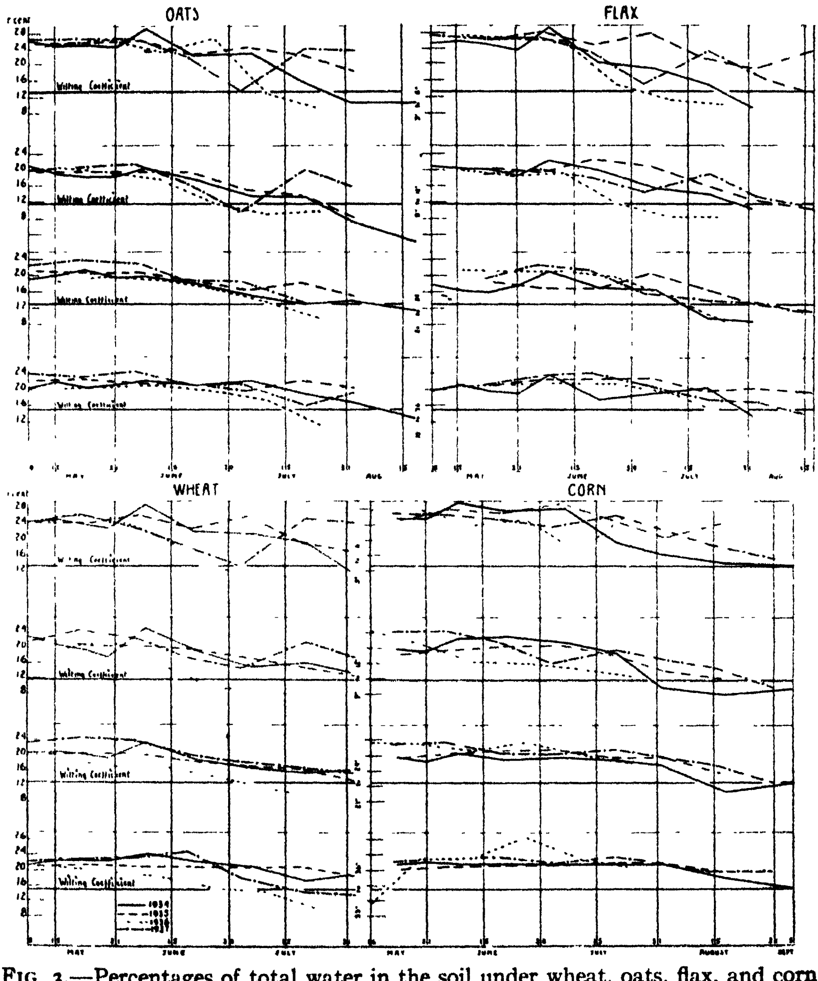

FIG. 3.—Percentages of total water in the soil under wheat, oats, flax, and corn and average wilting coefficients at depths of 3 to 6 inches, 9 to 12 inches, 21 to 24 inches, and 33 to 36 inches for 1934–37.

the planting of the new crop the following spring is given in the first column of Table 3. From this table and from Fig. 3, it may be seen that, particularly in the dry year of 1936, the grain crops have been able to reduce the subsoil moisture below the computed wilting coefficient. Growth curves in Fig. 2 show that wheat continued its growth after the soil moisture at all depths sampled had been so reduced, and in oats, flax, and corn growth continued after soil moisture

at one or two depths had been so reduced but not when it fell below the wilting coefficient at all depths.

In general, the available water supply in the soil from the middle to the latter part of the season was greater for corn than for any other crops studied (Fig. 3 and Table 3). During 1936, a season of low rainfall, the moisture content in the soil during the latter part of the season was low for wheat, oats, and flax but nearly as great in the corn plats as for other years.

It is evident that there is a trend toward exhaustion of soil water during the 1937 growing season even with more than average rainfall.

The mean temperatures for the intervals between measurements of the plants, the mean temperatures for each month during the growing season, and the average mean temperatures for 26 years are reported in Table 5. A comparison of monthly means for each year with the average shows (a) that 1934 was about average after a very warm May; that (b) 1935 was considerably colder than average in May and June, very much warmer in July, and slightly warmer in August; that (c) 1936 was warmer than average all season, July being the warmest month in 27 years of record; and that (d) 1937

TABLE 5.—*Mean temperatures for the intervals between dates given and averages for four summer months during growing seasons 1934–37 and 26-year average.*

1934	Temperature, °F	1935	Temperature, °F	1936	Temperature, °F	1937	Temperature, °F	26-year av.
May 17	62.8°	May 20	57.2°	May 19	63.7°	May 7	59.6°	
24	59.0°	27	56.2°	26	68.1°	15	53.2°	
31	72.8°	—	—	—	—	23	52.4°	
—	—	—	—	—	—	29	65.2°	
Mean	63.0°		51.4°		61.4°		57.4°	54.6°
June 6	60.1°	June 6	53.4°	June 3	60.2°	June 5	62.5°	
13	70.3°	11	59.9°	9	64.3°	12	54.6°	
20	65.8°	17	62.3°	16	64.5°	19	67.4°	
26	69.3°	24	63.2°	23	68.9°	26	70.4°	
—	—	—	—	30	66.8°	—	—	
Mean	64.4°		60.7°		64.4°		63.8°	64.2°
July 5	64.2°	July 2	74.1°	July 7	84.1°	July 3	66.5°	
13	69.7°	9	71.2°	14	87.1°	10	74.8°	
19	76.1°	16	72.3°	21	75.2°	20	68.3°	
25	71.3°	22	76.1°	28	74.3°	24	71.5°	
—	—	29	74.4°	—	—	—	—	—
Mean	69.8°		74.2°		78.7°		70.2°	69.7°
Aug. 1	71.1°	Aug. 7	71.7°	Aug. 11	73.0°	Aug. 2	69.4°	
8	71.3°	13	74.8°	13	72.0°	7	74.6°	
11	73.5°	20	65.1°	—	—	14	73.2°	
16	70.4°	—	—	—	—	21	70.4°	
25	56.7°	—	—	—	—	—	—	
Mean	66.6°		67.2°		69.4°		72.6°	66.7°

was about average except for a hot August and a warm May. August was the warmest on record.

In Table 6 are reported yields in bushels of grain and pounds of straw, weight per 1,000 seeds, and number of seeds per spike or boll.

TABLE 6.—*Yield of grain and straw, weight per 1,000 seeds, number of seeds per spike or boll, and height of plant.*

Crop	1934	1935	1936	1937	Average height*
Wheat:					
Yield in bushels	22.4	17.1	5.9	33.4	
Wt. per 1,000 kernels, grams	26.3	27.4	20.4	20.0	
No. kernels per spike	28.9	26.7	24.5	20.0	
Wt. of straw and grain, lbs	3,628	2,737	1,264	7,020	
Wt. of grain, lbs	1,578	1,026	354	2,004	
Wt. of straw, lbs.	2,050	1,711	910	5,016	
Ht. in inches	37.4	34.3	27.5	36.7	30
Oats:					
Yield in bushels	62.5	30.5	—	67.1	
Wt. per 1,000 kernels, grams	25.3	24.7	9.2	25.3	
Wt. of straw and grain, lbs	4,069	3,139	1,197	5,600	
Wt. of grain, lbs	2,000	976	—	2,147	
Wt. of straw, lbs.	2,069	2,163	1,197	3,453	
Ht. in inches.	50.6	43.1	25 6	42.5	41
Flax:					
Yield in bushels	12.7	10.2	3.8	11.0	
Wt. per 1,000 seeds, grams	3.9	5.2	3.3	5.9	
No. seeds per boll	7.4	6.6	5.0	6.3	
Wt. of grain and straw, lbs	1,776	1,694	699	3,180	
Wt. of grain, lbs	711	571	212	616	
Wt. of straw, lbs.	1,065	1,123	487	2,564	
Ht. in inches	27.8	25.0	21.5	21 9	20
Corn:					
Yield of forage in lbs	7,300	6,963	2,482	3,762	
Ht. in inches. .	73.1	78 7	46.1	61.0	61

*Nine-year average for wheat, flax, and corn, 1929–1937; 13-year average for oats, 1925–1937.

The four years' data reported in Table 6 represent too short a period to make advisable any statistical treatment or definite conclusions. Some apparent tendencies, however, may be pointed out. The weight of straw seems associated rather directly with yield in wheat and to a less extent in oats and flax. Weight per 1,000 seeds is associated rather directly with yield in oats and to a less extent in flax. The association is much less apparent in wheat. The number of seeds per boll is associated directly with yield in flax, but the association between number of kernels per spike and yield of wheat is not so apparent.

If the total precipitation from the harvest of one season to the harvest of the next is considered (Table 3), there is an apparent association between yield and precipitation for wheat, oats, and flax in 1935 and 1936, but not in 1937 and 1934 unless the precipitation during the preceding year of fallow is disregarded. These associations may be more apparent than real, however.

Since 1936 was a year of extreme heat and drought, its significance in any correlation study is not important even though definite. The heat of July 1936 blasted oats blossoms before they were fertilized so that grain yields were impossible and it probably injured wheat.

The apparent association between yield and precipitation in 1935 may be accidental since the temperatures of July were high and may have reduced the yield. This is borne out by the fact that the total moisture in 1935 did not fall below the wilting coefficient in the July samples and as an average of all depths there was as much available water in the soil for all crops on corresponding dates in July 1935 as in 1934 or 1937 with the one exception of July 20, 1937, for wheat. The lack of association between yield of flax and precipitation may also be explained by the injurious effect of a hot August that retarded normal growth and delayed ripening.

In corn there appears to be no association of yield of forage with rainfall and not uniformly with height. The tall growth in 1935 may be explained by the combination of high temperatures and adequate moisture, while the shorter growth in 1937 with more than average moisture may have been due to temperatures lower than optimum; the high temperatures of August coming too late for an early variety such as Northwestern Dent (Crookston strain).

TABLE 7.—*Dates of heading or flowering and ripening and notes on disease of wheat, oats, flax, and corn 1934–1937.*

Crop	Year	Date*	Date ripe	Disease notes
Wheat	1934	June 26–July 5	Aug. 5	2% stem rust on 1 plant; others trace or none.
Oats		———	Aug. 16	25% stem rust on 3 lodged plants; others none.
Flax		July 5	Aug. 8	Trace stem rust on 1 plant; others none.
Corn		Aug. 8	Aug. 30	
Wheat	1935	July 2–July 9	Aug. 7	2% stem rust on 2 plants; others trace or none; moderate leaf rust.
Oats		July 16	Aug. 7	10% stem rust on 1 plant; 5% on 2 plants; others trace or 0; heavy crown rust on all plants.
Flax		July 9	Aug. 12	
Corn		July 16	Aug. 28	
Wheat	1936	June 23–June 30	July 28	
Oats		July 11	July 28	
Flax		June 30–July 7	July 28	
Corn		July 14	Aug. 4	Dried up.
Wheat	1937	July 3	Aug. 2	No stem rust; light leaf rust; 1 plant affected by root-rot.
Oats		July 10	Aug. 7	15% stem rust on 1 plant; light crown rust on all.
Flax		July 3–July 10	Aug. 21	Trace of stem rust on 6 plants; others none.
Corn		July 24–Aug. 2	Aug. 31	

*Date of heading in wheat and oats; full bloom in flax; tasseling in corn.

In Table 7 are reported notes on diseases affecting the crops. Thatcher and Anthony are resistant to stem rust (*Puccinia graminis tritici* and *avenae*). The infection reported included pustules of the resistant type only. Although Thatcher is not resistant to leaf rust (*Puccinia triticina*) and Anthony is not resistant to crown rust (*Puccinia coronata avenae*), comparison of number of kernels produced and weight per 1,000 on individual plants with and without infection indicated no injury from the disease in the amounts found in these trials. Flax wilt (*Fusarium lini*) did not appear in any of the plats and only a trace of stem rust (*Melampsora lini*) was ever present. More complete control of the rust might have been accomplished by dusting with colloidal sulfur, but it is believed that the disease factor in these investigations was of negligible importance. There was no insect or mechanical injury so that differences in growth and yield may be attributed at least importantly to meteorological factors.

Phenological data reported in Table 7 are of interest when considered in relation to the growth curves shown in Fig. 2.

SUMMARY

1 Growth curves and data on yields of wheat, oats, flax, and corn, together with weight per 1,000 kernels of wheat, oats, and flax during a period of four years, 1934-1937, are presented.

2. Temperature and precipitation data and graphs of soil moisture in the plats on which these crops were grown are presented.

3. Methods employed in this study are described in detail.

4 The period of investigation is too short to warrant a statistical analysis or definite conclusions.

5. Certain tendencies may be observed as follows· (a) In wheat there is a positive and fairly consistent association between weight of straw and yield of grain when the four years' data are considered. The association is much less apparent in oats and flax. (b) Weight per 1,000 kernels is associated rather directly with yield of oats grain and to a less extent in flax. The association is much less apparent in wheat. (c) The number of seeds per boll is associated directly with yield of flax seed, but the association between number of kernels per spike and yield of wheat grain is not apparent. (d) Associations of yield with precipitation may be more apparent than real since the temperature factor is important. (e) In corn there appears to be no association of yield of forage with rainfall and not uniformly with height.

6. Measurement of several individual plants present some important advantages over mass samples, as follows: (a) Comparison of individuals in growth, yield, and disease can be made. (b) Individuals accidentally injured or killed are easily detected and eliminated from consideration. (c) Variation due to individual differences may be measured and used for determination of this error. (d) Individuals may be selected in areas of full stand and free from weeds, ant hills, animal droppings, etc. (e) The same samples may be used for each determination.

7. The available soil moisture offers a single factor which represents a resultant of various elements of environment.

8. In 1936, growth continued in wheat after soil moisture at all depths sampled had been reduced below the computed wilting coefficient.

9. In oats, flax, and corn growth continued after soil moisture at one or two depths had been so reduced.

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ZONAL DISTRIBUTION OF NITRATES AND ITS EFFECT ON NODULATION OF SOYBEANS[1]

George Z. Doolas[2]

THOUGH nitrates and ammonium salts as fertilizers have been credited with inhibitive effects on nodulation by legumes, their effects on the production and distribution of nodules as a consequence of their varied local concentration in the growing medium have not been adequately investigated.

Strowd (3)[3] and Wilson (4) concluded from their studies with soybean plants, by dividing their roots in such a way that a number of them were grown in nitrate-bearing and a number of them of the same plant in nitrate-free part of the same medium, that the peculiar injurious effects by nitrates on nodulation are entirely local in character.

Possibly the nodulation effects by different concentrations of nitrates would be different if the same root were growing through both nitrate-free and nitrate-bearing zones in the medium. Since by this method nitrates absorbed in the distal part of the root must pass through all points lying towards the stem, it would be possible thereby to determine whether the effects are distinctly local or of a more general nature. This arrangement of growing the same root in two differently treated media was used in the following study for its possible contribution to our knowledge about the nature of the inhibitive effects by nitrates on nodulation of soybeans.

EXPERIMENTAL

Soybean plants were grown with their roots extending through soil to one part of which nitrates had been added and one part of which received no nitrate. This mode of division of the soil and the roots was accomplished by growing the soybean seedlings in soil in a paraffined screen pot immersed in a gallon jar of soil as previously described (1).

The soil used was Putnam silt loam collected from a field cropped to soybeans. The reaction of this lot of soil was altered from 5.6 pH to 6.8 pH by the addition of a mixture of 80% of finely ground lime and 20% of 60-mesh limestone. Into this lot of soil there were thoroughly mixed 15 parts of P_2O_5 as mono-calcium phosphate and 30 parts of MgO as magnesium sulfate per million parts of soil as calculated on the dry basis. The entire mass of this soil was then thoroughly inoculated with ***Rhizobium Japonicum.***

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[3]Numbers in parenthesis refer to "Literature Cited", p. 914.

In the spring[4] two series of six pots, each consisting of a gallon jar of soil and one paraffined-screen pot of soil immersed into it, were prepared in duplicate.

In the paraffined-screen pot were placed 435 grams of soil and in the space about it in the gallon jar 2,000 grams. To the one series there were added only to the gallon jar 52, 83, 104, 144, 225, and 300 parts per million of soil of nitrogen as calcium nitrate. This was designated series A. The same concentrations were also added to the soil in the centrally immersed paraffined-screen pot and were designated series B. This gave equal concentrations of nitrate nitrogen in the treated zones but wide differences in the total nitrogen applied according to the differences in weights of soil in the two parts of the pot. In series B with 435 grams in the screen pot treated with nitrate, the total amount applied was only slightly more than one-fifth of that in series A where 2,000 grams of soil were so treated.

RESULTS

The data showing the number of nodules on the root segments of the inner and outer soil zones, the nodules per pot, their dry weights, and the weights of the plants are presented in Table 1. The average values for pots 4, 5, and 6, together with their comparative values calculated by fixing those for the check or untreated pot at 100 are shown in Table 2. Figs. 1 and 2 show the characters of the nodulation and root development of the nitrate-treated and the nitrate-free root segments of series A and B, respectively.

TABLE 1.—*Growth and nodulation of soybeans in consequence of varied zonal concentrations of calcium nitrate in the soil.*

Pot No.	Nitrate nitrogen added		Nodules per plant			Dry weight of nodules, mgms			Dry weight of tops per pot, grams
	P.P M.	Mgms	Outer zone	Inner zone	Total per plant	Outer zone	Inner zone	Total per pot	
			Series A—Outer Zone						
1	52	104	6.0	31.5	37.5	48.0	300	348	6.3
2	83	166	3.4	24.0	27.4	27.0	45	72	5.2
3	104	208	0.8	35.0	35.8	0.1	87	87	7.0
4	144	288	1.0	34.0	35.0	0.01	60	60	5.8
5	225	450	0.0	27.5	27.5	0.0	45	45	6.8
6	300	600	0.1	22.0	22.1	0.0	23	23	5.7
			Series B—Inner Zone						
1	52	21	3.6	36.0	39 6	30	330	360	4.4
2	83	33	7.0	28 5	35.5	50	192	242	5.0
4	144	57	3.5	24.5	28.0	23	150	173	4.7
5	225	90	9.8	23.2	33.0	63	222	285	6.0
6	300	120	14.0	19.0	33.0	57	140	197	5.9
Check	0	0	7 5	32.0	39.5	39.0	362	401	4.6

[4]This experiment was tried in the winter with 10, 32, 52, 104, and 144 parts of nitrogen per million parts of soil. The plants made meager growth and grew tall and slender. Only a few plants produced nodules which were very few and very small. The nitrates did not affect nodulation at this season. Such abnormalities suggested the influence of unsuitable light conditions and therefore this experiment was repeated in the spring.

TABLE 2.—*Averages and comparative values of weights of tops, numbers and weights of nodules of pots 4 to 6 of each of two series, and of the check.*

Series	Nodules per plant			Dry weight of nodules per pot, mgms			Dry weight of plants per pot, grams
	Outer zone	Inner zone	Total	Outer zone	Inner zone	Total	
				Averages			
A	0.4	27.8	28.2	0.0	44	44	6.1
B.	9.0	22.0	31.0	47.6	171	218	5.5
Check	7.5	32.0	39.5	39.0	362	401	4.6
				Comparative Values			
A	0.1	87	72	0	12	11	132
B	120	70	79	124	47	54	119
Check	100	100	100	100	100	100	100

ZONAL INFLUENCE OF NODULATION

It is evident from these results that both the numbers (formation) and the weights (development) of the nodules were decreased in the

FIG. 1.—Soybean roots with segments (above) grown in the soil zone without nitrate additions and (below) the zone with added calcium nitrate as increasing amounts from left to right.

zones of nitrate placement in both series roughly according to the increase in concentration of nitrate nitrogen. In only one pot, No. 5, were the results not in agreement with this relationship. In concentrations of 144 mgms and more of nitrate nitrogen in the outer soil zone (series A), the applications of nitrate checked the formation and development of nodules therein almost entirely; but the nitrates added in the same concentration to the inner soil zone (series B) did not check nodule formation and development in this zone so completely.

FIG. 2.—Soybean roots with segments (above) grown in the soil zone with added calcium nitrate as increasing amounts from left to right and (below) the zone without nitrate additions.

The more severely depressive effects by the larger amounts of nitrates placed in the outer soil zone (series A) extended to depress the development, or weight, of the nodules in the inner or nitrate-free zone. This is evident from the comparative values in Table 2 of the averages of the nodule weights. For the inner soil zone of series A the figure was only 12, while for the untreated check it was 100. The effect on reducing the number of nodules did not extend itself so pronouncedly into the inner or nitrate-free soil zone.

That the nitrates reduced the weight, or development, of the nodules more than they reduced their numbers, or formation, is shown in Table 3 consisting of some data assembled from Table 2. As for the weights of the nodules in comparative values, these are much lower in the zone of application than in the pot as a whole. As regards the number of nodules, those in the treated zone are not so much less

than the total number in the pot. In these respects these results agree in principle with those obtained by Giobel (2).

TABLE 3.—*Nodule numbers and weights in the nitrate-treated zone as compared to total nodules produced.*

Series	Comparative values	
	Weight	Number
A, outer zone, nitrates added	0	0.1
A, entire plat, total	11	72.0
B, inner zone, nitrates added	47	70.0
B, entire pot, total	54	79.0

EFFECT OF TOTAL AMOUNT OF NITRATE NITROGEN ON NODULATION

The total weights of nodules per pot tended to decrease not only according to the increase in the concentration of the nitrate nitrogen locally but also according to the total amount of nitrogen offered the plant. Since series B received only about one-fifth as much nitrogen per plant as series A, the comparative values in Table 2, namely, 100, 47, and 12 for the averages of the nodule weights in the pots 4 to 6 for the check, the series B, and the series A, respectively, show clearly the declining nodule weights with increasing amounts of total nitrogen offered the plants. From these data it appears, therefore, that the nitrates exercise injurious effects more on the development, or weight, of the nodules than on their formation, or numbers; and that the influence is greater not only with increasing concentrations but is more clearly related to the amount of nitrogen offered the plant.

The amounts of nitrate added controlled also the total weights of the tops as shown by the greater weights of tops in series A, receiving the larger total amounts of nitrate nitrogen

DISCUSSION

The injurious effects on nodulation by the larger applications of nitrate nitrogen were found to be not entirely local. When the outer root segments were treated with nitrate, this depressed both the formation and the development of nodules in these root segments and extended the depressive effects significantly to the development but insignificantly to the formation of nodules within the non-nitrate-treated segments. The nitrate exerted its injurious effects on the development of nodules on those parts of the root lying along the path of the nitrate on its way to the stem from the points of absorption when the larger amounts of nitrate were used. This effect did not move in the reverse direction or towards those parts lying in the opposite direction from the points of absorption in the case of series B where the total nitrate supply was smaller but of the same concentration.

These results seem to indicate that the agency acting adversely on nodulation exerts its effect by hindering the development of the nodules over the entire root system. The total weight and the size of the nodules decreased with the increase in the total amount of nitrate

per plant, while the numbers were not so decreased. This indicates that the nitrate acts from within the plant after being absorbed and inhibits the development of the nodules without necessarily increasing the resistance by the plant to the entrance of the bacteria into the root tissue.

SUMMARY

Studies made of the effects of varying the nitrate concentration in two soil zones on the nodulation by soybeans gave decreased numbers and weights of nodules in the zones in which the nitrates were added. Such effects carried into the nitrate-free soil zone to decrease the weight of the nodules when the applications of nitrate were larger. When the same concentration of nitrates was applied in the inner zone and consequently less total amount of nitrogen, these effects were not transmitted so distinctly to the distal parts of the roots.

In general, the depressive effects were more pronounced on the weight or development than on the numbers of nodules. The decrease in total weight of nodules on the entire root system, as well as on the segments, was governed more by the total amount than by the concentration of nitrate nitrogen applied.

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THE USE OF MORPHOLOGICAL CHARACTERS AS COMPARED WITH FLUORESCENCE TESTS WITH ULTRA-VIOLET LIGHT IN CLASSIFYING THE RYEGRASSES (*LOLIUM* SPP.) OF WESTERN OREGON[1]

H. H. RAMPTON[2]

RYEGRASS (*Lolium* spp.) is grown extensively for seed and forage in western Oregon. Over 90% of the ryegrass seed grown in the United States is produced in the Willamette Valley. The major portion of this seed is used for winter golf courses, winter lawns, and annual pastures in the southern states.

Domestic or Oregon ryegrass varies widely in plant and seed characters and is usually classified as *Lolium multiflorum* Lam. The Division of Seed Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture from seed characters considers it to contain the Italian type as grown in Europe and New Zealand, the Argentine-Italian type, and the perennial or English type. The seed is so variable in appearance that seed analysts are sometimes uncertain as to its definite classification. The general belief that all awnless ryegrass seeds are of the English or perennial type has resulted in the assumption that domestic or Oregon ryegrass contains considerable perennial stock.

The studies as outlined were made in an attempt to determine (a) the value of the fluorescence test in the classification of domestic ryegrass, (b) the approximate percentage of the perennial type in domestic ryegrass, and (c) possible types into which domestic ryegrass may be classified.

REVIEW OF LITERATURE

Schoth and Enlow[3] reported that domestic or Oregon ryegrass may be pure Italian, but is usually a mixture, predominantly Italian. Various combinations of Italian ryegrass and the perennial type may occur. They ascribed most of the intermediate types in domestic or Oregon ryegrass to natural crossing of the Italian and perennial types.

Hessing (7)[4] studied the genetics of ryegrass and concluded that while many types are relatively constant, great variation of characters occurs and in numerous combinations.

[1]Contribution from the Oregon Agricultural Experiment Station, Corvallis, Ore., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Published as Technical Paper No. 286 Abstract of a thesis presented to the Department of Farm Crops, Oregon State College, in partial fulfillment of the requirements for the master's degree. Received for publication August 8, 1938.

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[3]SCHOTH, H. A., and ENLOW, C. R. The ryegrasses. U. S. D. A. mimeographed Circ. of Information. March, 1933.

[4]Figures in parenthesis refer to "Literature Cited", p. 922.

Italian and perennial ryegrass were described by Breakwell (1) Jepson (10), and Levy and Davies (11). The most important characters are listed as follows:

Lolium perenne L.—perennial ryegrass:
- Plants long lived
- Leaves mostly basal, numerous, comparatively narrow, folded in the bud
- Culms and convex side of rachis smooth
- Spikes erect, slender
- Spikelets not much longer than the outer glume
- Lemmas awnless
- Seedling growth slower than Italian
- Color of foliage dark green

Lolium multiflorum Lam.—Italian ryegrass:
- Plants short lived, taller than the perennial type
- Leaves borne mostly on the stems, rolled in the bud, wider and less numerous than the perennial type
- Culms and convex side of rachis often rough
- Spikes larger than the perennial type
- Spikelets much longer than the outer glume
- Lemmas awned, lower lemma of spikelet may be short awned or awnless
- Seedling growth rapid
- Color of foliage lighter green than the perennial type

Hayes and Garber (5) showed that in *Lolium multiflorum* 10.3% of the florets set seed when self fertilized and that 78.8% seed setting resulted from open pollination.

Jenkin (8, 9) found Italian and perennial ryegrass to be normally wind pollinated. Successful artificial crosses of *Lolium perenne* L. $\times$ *L. multiflorum* Lam. were reported. Hellbo (6) reported that Italian and perennial ryegrass are easily crossed.

Hellbo (6) working in Denmark, reported that Italian ryegrass seeds coming through the threshing and cleaning process in an awnless condition may be distinguished from perennial ryegrass seeds by certain characters of the lemma, palea, and rachilla and by the seed shape. Foy (4) of New Zealand and Colbry (2) of Oregon found the method used by Hellbo (6) to be unsatisfactory when applied to commercial ryegrass seed grown in New Zealand and Oregon, respectively.

Foy (4) applied the fluorescence test to the ryegrasses of New Zealand. He found that the seedling roots of Italian ryegrass produced fluorescence upon a white filter paper germinating base when placed over filtered ultra-violet light. Perennial ryegrass seedlings produced no fluorescence and seedlings of intermediate types were variable in reaction. Seedling fluorescence was found to be directly associated with the short life of ryegrass.

Linehan and Mercer (12, 13) of Ireland, after making studies similar to those reported by Foy (4), stated that awned seeds usually produced fluorescent seedlings that developed into normal Italian type plants. Non-fluorescent awnless seeds usually produced normal perennial plants. They considered the proportion of non-fluorescent awnless seeds in a lot of seed to be an approximate measure of the amount of perennial seed present.

These investigators reported fluorescence to be dominant in the F_1 progeny of fluorescent $\times$ non-fluorescent parent plants, and segregating in the F_2 progeny in an approximate 3 fluorescent to 1 non-fluorescent ratio. They found no evidence of linkage between fluorescence and awn presence or plant longevity.

Corkill (3) studied the inheritance of fluorescence in ryegrasses. His results indicated that fluorescence depends on a single Mendelian factor, segregating in the progeny of a hybrid plant in a 3 fluorescent to 1 non-fluorescent ratio.

Foy (4) stated that there is no definite knowledge of the substance responsible for fluorescence of reacting ryegrass seedlings. He suggested that the characteristic fluorescence may be due to the product of a reaction between an exudate, perhaps an enzyme, of the seedling root and filter paper germinating base.

EXPERIMENTAL METHODS

Nursery and laboratory trials were conducted with 288 lots of domestic, "Oregon Wild," imported Italian, and imported and Oregon-grown perennial ryegrass seeds obtained from the principal ryegrass seed-producing regions of the world.

The nursery planting was made on November 4, 1931, in rows 16 feet long, spaced 2 feet apart.

NURSERY OBSERVATIONS

Field observations on the nursery were made periodically from time of seedling emergence to April 20, 1933. Field notes were recorded on persistence, winter-hardiness, growth type, dates of spike emergence, flowering, and seed maturity, vigor, and plant height.

In 1932, 10 representative single plants were harvested from each of 59 representative lots in the nursery at the time of seed maturity. These were cured and stored for later laboratory observations including fluorescence tests of germinated seeds and detailed plant observations covering plant height, number of internodes, culm diameter, stem texture, spike length, number of spikelets per spike, length of the outer glume, and awn length.

FLUORESCENCE TESTS WITH ULTRA VIOLET LIGHT

The equipment used in this test was the same as used for similar work by the Division of Seed Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture.

The fluorescence test was applied to seedlings of some of the original seed lots of domestic, imported, and Oregon-grown perennial, Imported Italian, Argentine, and "Oregon Wild" ryegrass, and also to their 1932 nursery-grown progeny.

Germinating and testing was done in the laboratory. Each test was conducted with duplicated 100 seed samples placed on moist discs of white filter paper in 3½-inch petri dishes, each dish containing 25 seeds. Counts of fluorescent seedlings began on the fifth day. This work was done at night because complete darkness aided in making accurate counts. All reacting seedlings did not fluoresce at the same growth stage, so counts were made at 2-day intervals until the eighteenth day.

RESULTS

THE NURSERY

Seedlings of domestic ryegrass emerged about 6 days earlier than any of the other lots and made the most rapid winter growth. Perennial ryegrass seedlings grew little in height during the winter but made considerable crown development.

Nursery observations during 1932 gave little evidence in support of the general belief that much perennial stock exists in domestic rye-

grass. The domestic ryegrass plants were, however, extremely variable in appearance. Wide variations in width, position, and number of leaves, general growth habit, color, vigor, number and texture of culms, spike type, and awn character were observed. Fig. 1 shows several common variations of spike type found in domestic ryegrass.

Only a small number of plants in domestic ryegrass possessed the narrow dense dark green leaves, comparatively short culms, and entirely awnless seeds characteristic of the perennial type. These were chiefly confined to a few lots, particularly lot No. 37, that appeared to be about 90% ordinary domestic and 10% perennial ryegrass.

These observations were further substantiated after the severe winter of 1932–33, when domestic ryegrass was almost 100% winter-killed and perennial ryegrass survived. Table 1 shows winter survival of a number of the lots in this trial. All perennial ryegrass lots were quite winter-hardy. The domestic lots in Table 1 showed 0 to 10% winter survival. Lot No. 37 survived 10% and was the only one of this group exhibiting the morphological characters of perennial ryegrass in the surviving plants.

Italian ryegrass lot No. 46 imported from Scotland survived 75%, indicating it to be hardier and perhaps naturally longer lived than domestic ryegrass. No perennial type plants were observed in this lot.

"Oregon Wild" ryegrass lot No. 66 had 60% winter survival. Most of the surviving plants were perennial-like in appearance. This observation checked quite closely with general observations of wild ryegrass plants growing along roadsides, fences, and in waste areas. This wild stock contains a fairly high percentage of perennial-like plants, many of which bear definitely awnless seeds. These plants were especially prominent in March, following the severe winter of 1932–33 when most domestic ryegrass was winter killed. The presence of this type of ryegrass growing wild in a great many places suggests that perennial ryegrass may have been an important component of the ryegrass seed crop at an earlier date. Some authorities believe this to have been the case; the perennial ryegrass gradually losing its identity in commercial seed fields because of the more profuse seeding qualities of domestic ryegrass and as a result of natural hybridization. On this basis, the wide variation in domestic ryegrass might be explained.

Plant observations in the laboratory showed perennial ryegrass to be invariably smooth-stemmed, quite constant in spike characters, and in general, comparatively uniform. Imported Italian ryegrass was also quite uniform, particularly with respect to length of the outer glume and the long awned character. Stem texture was variable. Domestic ryegrass showed wide variation in all characters studied. The variation between different lots was much less striking than the variation within lots. Awn studies showed variation from long heavy awns to awnless seeds. Careful checking showed that many weak-awned domestic ryegrass plants lost their awns in the field, chiefly as a result of wind agitation.

Attempts to classify domestic ryegrass into distinct types were abandoned when it became apparent that classification would be of little practical value because of the numerous plant types involved.

FLUORESCENCE TESTS WITH ULTRA-VIOLET LIGHT

Certain substances have the property of absorbing the short, invisible ultra-violet rays and omitting longer, visible light rays. This

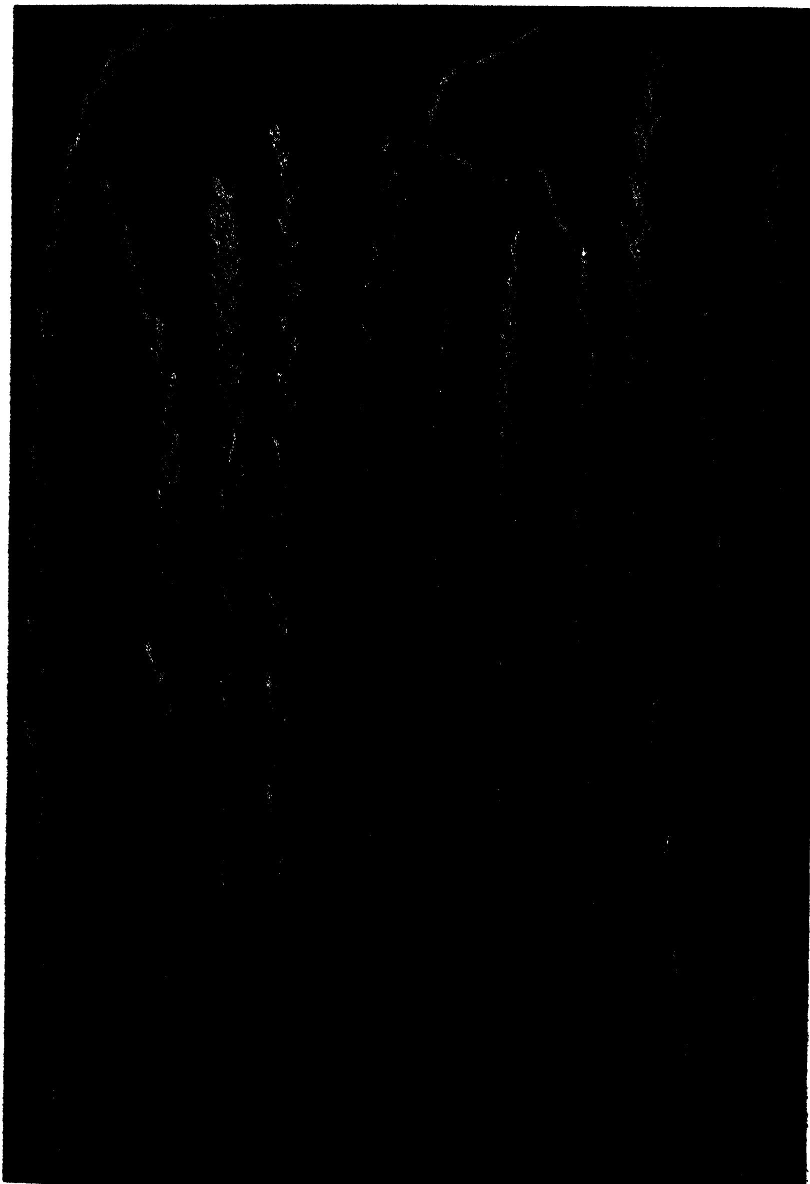

FIG. 1.—Variations of spike type commonly found in Oregon-grown domestic ryegrass.

is known as fluorescence. The results of fluorescence tests applied to the seedlings of some of the ryegrasses under trial are shown in Table 1.

TABLE 1.—*Percentage winter survival and results of fluorescence tests on seedlings of various lots of ryegrass including the 1931 (original) lots and their 1932 nursery progeny.*

Lot No.	Year	Origin and species	Survival winter 1932–33 %	Fluorescent seedlings %
1	1931	Domestic *L. multiflorum*	5.0	88.0
1	1932	Domestic *L. multiflorum*		92.0
2	1931	Domestic *L. multiflorum*	0.0	87.0
2	1932	Domestic *L. multiflorum*		93.0
3	1931	Domestic *L. multiflorum*	5.0	90.0
3	1932	Domestic *L. multiflorum*		94.0
4	1931	Domestic *L. multiflorum*	0.0	92.0
4	1932	Domestic *L. multiflorum*		93.0
5	1931	Domestic *L. multiflorum*	0.0	87.0
5	1932	Domestic *L. multiflorum*		95.0
6	1931	Domestic *L. multiflorum*	0.0	83.0
6	1932	Domestic *L. multiflorum*		92.0
7	1931	Domestic *L. multiflorum*	0 0	93.0
7	1932	Domestic *L. multiflorum*		100.0
8	1931	Domestic *L. multiflorum*	5.0	89.5
8	1932	Domestic *L. multiflorum*		94.0
9	1931	Domestic *L. multiflorum*	0.0	86.5
9	1932	Domestic *L. multiflorum*		95.0
10	1931	Domestic *L. multiflorum*	0.0	91.0
10	1932	Domestic *L. multiflorum*		91.0
11	1931	Domestic *L. multiflorum*	0 0	87.0
11	1932	Domestic *L. multiflorum*		92.0
12	1931	Domestic *L. multiflorum*	0.0	92.0
12	1932	Domestic *L. multiflorum*		94.0
37	1932	Domestic *L. multiflorum*	10.0	98.0
42	1931	Domestic *L. perenne*	90.0	13.0
42	1932	Domestic *L. perenne*		41.0
43	1931	Imported *L. perenne*	95.0	24.0
43	1932	Imported *L. perenne*		54.0
44	1931	Scotland *L. perenne*	95.0	18.0
44	1932	Scotland *L. perenne*		40.0
45	1931	N. Zealand *L. perenne*	85.0	50.0
45	1932	N. Zealand *L. perenne*		86.0
46	1931	Scotland *L. multiflorum*	75.0	80.0
46	1932	Scotland *L. multiflorum*		98.0
52	1931	Argentine *L. multiflorum*	0.0	76.0
52	1932	Argentine *L. multiflorum*		76.0
53	1931	N. Zealand *L. perenne*		0.0
54	1931	N. Zealand *L. perenne*		5.0
66	1931	"Oregon Wild" L. sp.	60.0	70.0

Differences in fluorescence of seedlings from the 1931 (original) and 1932 (nursery-grown) seed of the same lots were generally apparent. The averages of fluorescence for the lots Nos. 1 to 10 in Table 1 were 88.70 and 93.90% for the 1931 and 1932 crop seedlings, respectively, or a difference of 5.20%. These results seem to support the theory of Foy (4) who suggested that an enzyme may be responsible for the fluorescence of reacting seedlings. The enzyme activity of seeds is known to decrease with age.

When the results of the fluorescence tests on domestic ryegrass are used as a guide, only lot No. 7 and two others not recorded in Table 1 appear to be 100% non-perennial. A number of other domestic lots fluoresced 98%. Several awned non-fluorescent seedlings were observed in some of the tests.

Domestic lot No. 37 that appeared to contain about 10% of perennial ryegrass in the nursery fluoresced 98%. This indicated that some or all of the perennial type plants observed may have been intermediate forms having perennial-like plant characters but producing fluorescent seedlings. A 1931 seed remnant of this lot was not available for testing its fluorescence before being grown in the nursery. Colbry (2) reported 88.89% to 94.21% fluorescence in samples of domestic ryegrass seeds. The average of fluorescence for all 1932 lots of domestic ryegrass used in the trials was 94.20%.

The findings of Corkill (3), Foy (4), and Linehan and Mercer (12, 13) when applied to these data indicate that the domestic ryegrass used in these trials averaged approximately 5% perennial, or perennial and non-fluorescent intermediate forms, and 95% Italian and fluorescent intermediate forms of ryegrass. On the basis of nursery behavior, however, this domestic ryegrass contained less than 1% of perennial or intermediate forms resembling perennial ryegrass. Linehan and Mercer (12, 13) indicated that the fluorescence test may be used only for making approximate determinations in classifying ryegrass seeds. The findings of these investigators concerning the absence of linkage between fluorescence and awn presence account for the awned non-fluorescent domestic ryegrass seedlings observed.

Evidence was obtained of crossing between lots of domestic and perennial ryegrass in the nursery. A comparison of the fluorescent character of seeds of perennial ryegrass before and after being grown in the nursery indicated that crossing had taken place. A few lots of domestic ryegrass grown adjacent to lots of perennial stock also showed evidence of crossing.

"Oregon Wild" ryegrass fluoresced 70%. This observation checked in a general way with nursery and field observations and was considered to indicate the presence of perennial ryegrass.

SUMMARY AND CONCLUSIONS

Nursery trials and fluorescence tests were conducted with numerous lots of ryegrass seeds obtained from growers in western Oregon and from the important foreign ryegrass seed-producing countries.

Domestic ryegrass as commonly grown in western Oregon is a mixture of types, most of which are closely associated with the European Italian ryegrass type, and a few that are perennial-like. "Oregon Wild" ryegrass contains many perennial-like plants, suggesting that perennial ryegrass may have been an important component of the ryegrass seed crop in the past. On this basis, authorities sometimes explain the wide variability of domestic ryegrass.

There is little evidence in support of the belief that an appreciable quantity of perennial ryegrass now exists in commercial domestic ryegrass. The fluorescence test indicated that domestic ryegrass is

approximately 5% perennial or perennial and non-fluorescent intermediate forms of ryegrass. The nursery behavior, however, indicated less than 1% of perennial-like plants.

Domestic ryegrass and the Italian ryegrass of New Zealand and Ireland appear to be quite similar in reaction to the fluorescence test.

The fluorescence test cannot be used as an infallible guide in classifying questionable lots of Oregon-grown domestic ryegrass seed. Some of the domestic ryegrass seedlings used in these trials showed no fluorescence, even though they were chiefly not of perennial stock. An experienced seed analyst thoroughly familiar with the seed characters of the various ryegrass types can, in most cases, quite accurately evaluate such seed samples, but the fluorescence test is useful in the classification of the general run of domestic ryegrass seed and in making approximate determinations. It is also useful in serving as a check on the work of seed analysts.

Classification of domestic ryegrass into definite types was impracticable because of the numerous combinations of characters encountered.

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SHELTERBELT PLANTING REDUCES WIND EROSION DAMAGE IN WESTERN OKLAHOMA[1]

J. H. STOECKELER[2]

SHELTERBELTS of trees and shrubs have long been used in Russia, Italy, Hungary, and Canada and in certain fruit growing sections of our own Pacific Coast to give protection to crops and reduce wind erosion. They have been used to some extent in the subhumid Great Plains area where tree growing is a difficult proposition and success depends on correct choice of planting site, careful ground preparation before planting, proper selection of species, and clean tillage for three to 5 years after planting.

One of the most outstanding areas in the Great Plains in which tree planting has been carried on with considerable success for over 30 years is located in northeastern Greer County, Oklahoma, about 15 miles northeast of the town of Mangum. The writer will endeavor to record here for the benefit of those interested in wind erosion his observations of this planting program and a resumè of information obtained by personal interview with a considerable number of farmers in this vicinity.

CLIMATE, SOIL, AND CROPPING PRACTICES

The area under discussion has a mean annual rainfall of about 27 inches of which almost 70% falls between April 1 and September 30. The evaporation from a free water surface for the six summer months is close to 48 inches.

The soils are generally sandy and one of the predominant soils is the Miles series which has a loamy fine sand to sandy loam topsoil from 6 to 15 inches thick, lying over a sandy-clay subsoil. The sandy topsoil is an excellent "sponge" for the rapid absorption of rainfall which is stored in the more impervious subsoil where it is held within easy rooting depth of crops. It has been observed that if wind erosion removes this top layer of sandy soil, crop yields decrease considerably, due, very likely, to lower infiltration rate, higher runoff, and greater evaporation losses.[3]

The principal crops are cotton and several types of grain sorghums, such as kaffir and milo. Soybeans and cowpeas are used occasionally in rotations to build up the soil.

Yields of cotton vary according to season, but generally range between ¼ and ½ bale per acre. Kaffir and similar feed crops yield from 15 to 30 bushels per acre. Crop yields are good enough so that the land cannot be considered submarginal.

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[1]Contribution from the Lake States Forest Experiment Station, U. S. Department of Agriculture, University Farm, St. Paul, Minnesota. Maintained in cooperation with the University of Minnesota.

[2]Associate Silviculturist.

[3]It was suggested by Dr. H. J. Harper, Professor of Soils at the Oklahoma Agricultural Experiment Station, who reviewed this paper that loss of soil fertility, especially nitrogen, would also be a factor in reducing yields.

THE PROBLEM

The principal farming problem on the sandy soils in this area is sand drifting which causes damage by uncovering recently sown seed, cutting off tender shoots of crops when only a few inches high, and by burying or uncovering the plants. Besides the immediate damage to the crop, the value of the soil itself is reduced because of exposure of the subsoil and the formation of ridges and hummocks in the fields and along fence rows. Buildings and roads are also sometimes damaged by the drifting sand.

Cotton is especially susceptible to damage and is often planted from two to four times before a stand is obtained. This sometimes necessitates plantings made as late as June 15 to July 1, with the result that a 15 to 30% loss in yield may be incurred, chiefly due to late planting, with a high proportion of the flowers and unripe bolls injured by frosts in fall and consequently never maturing. If successful early planting is obtained, a much higher percentage of the crop matures and the total yield is considerably increased. The solution of the problem lies in protecting the soil and reducing the velocity of the wind during this critical period. (See Fig. 1.)

SOLUTION OF THE WIND EROSION PROBLEM

Over 30 years ago the farmers in this section of Oklahoma began the planting of single-row shelterbelts of cottonwood and mulberry spaced parallel to each other at distances of 1/8 to 1/4 mile apart and running in an east-west direction. This direction was chosen because it was at right angles to the direction of the most damaging winds which usually blow from the south. In some instances the east-west belts were supplemented with north-south windbreaks.

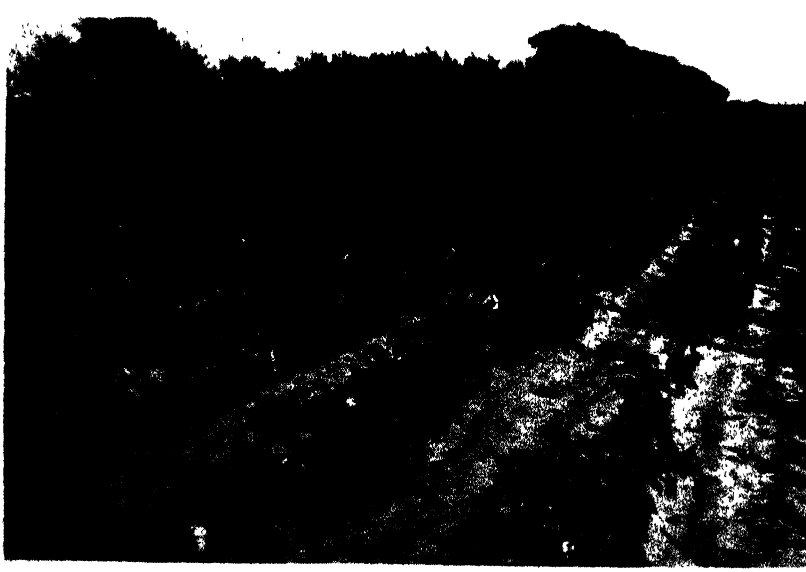

FIG. 1.—Cotton field on the Miles fine sandy loam protected by shelterbelt.

In addition, a system of strip cropping was adopted in which narrow strips of grain sorghum or other feed crops were alternated with cotton (Fig. 2). The strips varied from 5 to 10 rods in width and were planted in an east-west direction. It was observed that the strips of cane were of considerable value in later summer and fall in reducing the drifting of sand and were even effective in winter if left standing in the field.

The resulting program of tree planting and strip cropping has almost completely solved the wind erosion problem on many farms where serious crop losses had been sustained previous to these farmers' pioneering efforts in wind-erosion control.

FIG. 2.—Strip cropping with maize and cotton. Note shelterbelts in background.

DETAILS OF THE SHELTERBELT PLANTING

The planting of the shelterbelts by these farmers on their own resources, generally with no state or government subsidy, was prompted by several things. First, it was soon observed that strip cropping alone was not a complete solution of the sand drifting problem, especially in late spring during and immediately following planting of the row crop. Secondly, there was a need for fence posts and, to some extent, fuel.

Number of rows.—Inspection of many fields protected by shelterbelts showed that single or double rows of cottonwood or mulberry were practically as effective as windbreaks composed of 10 to 15 rows, required less labor, and occupied less ground.

Growth rate, cutting methods, and longevity of trees.—The trees grew at a surprising rate, such species as cottonwood attaining average heights of 30 to 40 feet in 8 to 10 years and an ultimate height of 60 to 70 feet in 30 years. (See Figs. 3 and 4.) Mulberry attains heights

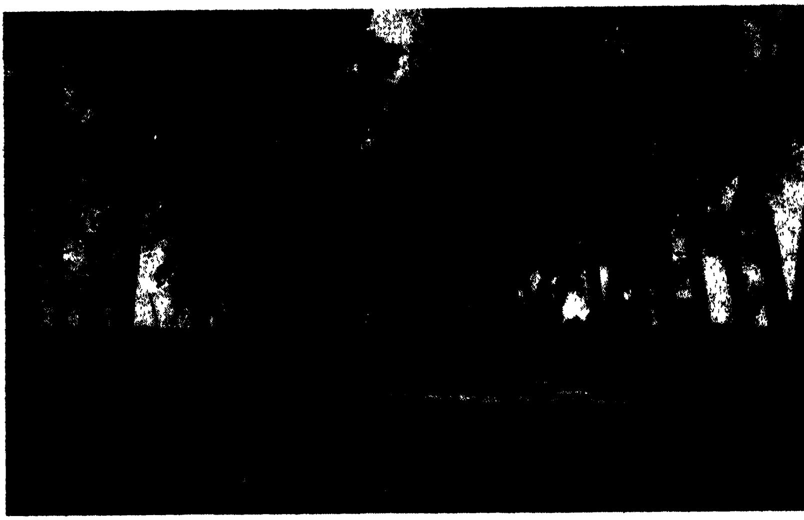

FIG. 3.—Cottonwood shelterbelt planted along road east of Willow, Oklahoma, serves dual purpose of beautifying road and reducing sand drifting on adjoining fields.

FIG. 4.—Exceptional growth on one-year-old Forest Service demonstration planting of honey locust and cottonwood near Mangum, Oklahoma. Trees are 7 to 10 feet high and already partially effective in reducing sand drifting.

of 20 to 25 feet in 10 years and is especially popular because it produces a desirable fence post in about 15 years.

A point of great interest to the writer was the manner in which single rows of mulberry trees were made to serve the dual purpose of

wind-erosion control and production of fence posts. The farmer merely cut a post out of the top of a fairly large mulberry tree, thus causing it to stool out, and thereafter a continuous supply of posts was obtained by judicious cutting of several stools or sprouts from each tree at intervals of 4 or 5 years. This could be done without seriously reducing the windbreak value of the tree. Where this modified "coppicing" method of cutting was utilized, the trees had a tendency to attain less than normal height and the parallel rows could not be over $\frac{1}{16}$ mile apart if they were to function effectively as windbreaks.

On the basis of existing shelterbelts on the sandy soils, it appears that the trees will keep in good vigor from 30 to 50 years and begin to be somewhat effective in wind erosion control when they are 3 to 5 years old.

A point of major importance in this section of Oklahoma is the fact that trees reach approximately twice the height and longevity on deep sandy soils that is attained on fine-textured soils, such as silt loams and clay loams.

Necessity of planting only on sandy soils.—In view of the above statement, a brief explanation is necessary. The Lake States Forest Experiment Station has determined on the basis of moisture samplings made in western Oklahoma that there is a much greater amount of available moisture within rooting depth of trees in the sandy soils and that there is deeper storage of the rainfall with consequent slower exhaustion of available moisture by deep-rooted plants. These observations are verified indirectly by Musgrave and Free[4] whose data on infiltration rates for the Cecil series show a marked superiority in favor of sandy soils, and it is logical to assume that the same trend would hold in western Oklahoma over a range of soil textures.

Finnell's[5] data on moisture utilization of the heavy soils in western Oklahoma indicate that as little as 25% of the total rainfall may be stored in the ground for actual use by crops. The inference to be drawn from his work is that fine-textured soils, in spite of their higher water-holding capacity, are actually much more droughty than sandy soils underlain by a sandy clay of reasonably good water-retention ability.

As a side light on this point, it might be of interest to state that the superiority for tree growing of sands over fine-textured soils is much more pronounced in the southern than in the central or northern part of the Great Plains, where rainfall does not attain the same intensity and where evaporation rate is less than farther south. The writer seriously questions the feasibility of shelterbelt planting on most of the fine-textured soils in the southern Great Plains as a wind control measure. Since the problem on such soils is largely one of storing moisture in the ground, such measures as terracing, contour listing, basin listing, summer fallowing, and crop rotation are much more

[4]Musgrave, G. W., and Free, G. R. Preliminary report on the determination of comparative infiltration rates of some major soil types. Trans. Amer. Geophys. Union, 18th Ann. Meet. 1937.

[5]Finnell, H. H. The utilization of moisture on the heavy soils of the southern Great Plains. Okla. Agr. Exp. Sta. Bul. 190. 1929.

practicable. Strip cropping is no doubt also of value in reducing wind erosion on these "tight" soils.

The difference in tree growth in soils of different textures is so striking in this part of Oklahoma that the casual observer can determine the texture of the soil from a distance of several miles merely by watching the relative abundance and height of the tree belts. Any upland area which is supporting numerous belts of tall vigorous trees will invariably be sandy in texture.[6] Conversely, on the fine-textured soils, especially on clay or clays loams, the belts are generally few, scrubby, short-lived, and riddled by borer damage.

SAPPING AND SHADING EFFECTS OF SHELTERBELTS

Numerous observations of windbreaks in this section of Oklahoma indicate that one- to three-row belts of trees will prevent or reduce crop production on a strip of land equal in width to approximately 1 to 1½ times the height of the taller trees. About two-thirds of the loss occurs on the north and one-third on the south side of the shelterbelt, the difference being due mainly to shading effect which is especially pronounced on the north side of the tree rows.

If this area is computed for a farm with an adequate system of windbreaks, it is found that eventually from 5 to 15% of the gross acreage will be removed from crop production, depending on the species, interval, and width of the protecting tree belts. Due allowance must be made for the fact that where crop rows are at right angles to tree rows planted along fence rows or property lines, not all of the idle land at the end of the crop rows can be justly charged as being taken up by the trees, because some bare land must be left for turning even if there are no trees planted along the property line. The point is that this waste space might better be occupied by a useful tree crop than by the usual stand of weeds or brush.

The writer asked a number of cotton farmers how it would be possible to justify the planting of the trees from a farm management viewpoint. The consensus of opinion was that the reduction of crop acreage due to sapping and shading effect of the trees was more than offset by protection to the soil, increase in yield on the remaining crop land, and value of the windbreak as a source of fence posts and fuel. Possibly they overrate the value of these shelterbelts, but it is probable that their cumulative experience over a period of at least 30 years and empirically determined deductions are technically sound.

SUGGESTED IMPROVEMENTS IN SHELTERBELT PLANTING

On the basis of observation of shelterbelt influences, supplemented by actual field data on moisture sampling and sapping and shading effects of the tree belts, several minor changes could be made to improve the benefits to be derived from tree planting in this section of the Great Plains, as follows:

[6]It must be recognized that on the extremely sandy areas, for instance dune sand, trees may be short-statured because of low water-holding capacity and lack of available nutrients. The term "sandy" as used here in connection with agricultural soils refers to soils which are classed as loamy sands or sandy loams.

1. A system of tree planting will be most effective if cropping areas are broken up into units from 10 to 40 acres in size and completely surrounded by shelterbelts, as shown in plans 1 to 4 in Fig. 5. If belts are planted only in an east-west direction, no protection is obtained against winds that are parallel in direction with the tree rows. The tree-planting plan followed need not be in as rigid a geometric pattern as shown. For instance, a farm may have a few very unstable knolls of sand which would be completely protected by windbreaks enclosing 10-acre blocks. The rest of the farm could be broken up into 20- or even 40-acre fields. Property boundaries, fence lines, topography, and land use will influence exact location of the tree strips.[7] Plan 2 is an especial favorite with farmers with whom demonstration plantings are made by the U. S. Forest Service in its Prairie States Forestry Project.

2. It would be much safer to adopt a two- or three-row belt because of the added protection given. It has been observed that cottonwood, as it approaches maturity, sheds its lower limbs, causing sizable gaps in the lower half of the belt which results sometimes in scouring of soil from the roots of the trees. Moreover, if a gap occurs in a single-row belt, there is created a channel through which the wind surges with increased velocity and destroys crops in a fan-shaped area on the lee side of the belt. Single rows of mulberry will, of course, make good windbreaks if the interval between belts is reduced. A fairly effective belt can be obtained by alternating cottonwood and mulberry trees in a single row.

On very unstable soils the east-west belts should not be over 1/8 mile apart, if they are to be effective. In other words, on such soils the effective zone of influence is about 10 times the height of the taller trees in the windbreak. Cottonwoods 70 feet high will generally prevent serious sand movement in a zone up to 700 feet on the lee side, providing the wind is fairly close to a right angle to the belt.

If no cottonwood is planted and single rows of mulberry or similar shorter growing species are used, the east-west belts should preferably be 1/12 to 1/16 mile apart.

3. It is advisable to use a greater variety of species, including honey locust, osage orange, green ash, apricot, jujube, and catalpa. Species like black locust, ailanthus, sand plum, or soapberry, which sucker profusely, might best be avoided, although some farmers think highly enough of black locust as a fence post producer so that they will plant it anyhow. Species producing fruit or nuts should be placed in the south row. Lilac, desert willow, and similar flowering shrubs are valuable next to roads. Dense, low-growing shrubs are not favored in interior windbreaks because of their tendency to build up a high ridge of sand along the shrub row. Hardy conifers, such as red cedar, Ponderosa pine, and Austrain pine, can be used to a limited extent along roads or near buildings.

4. Summer fallowing and similar moisture-storing measures should be used for at least one year before planting if the soil moisture to a

[7]On soils which are sufficiently fine-textured to yield any appreciable runoff from heavy rains, consideration should be given to the possibility of planting on the contour, as has actually been done on an experimental scale by the U. S. Forest Service in the plains region.

depth of 4 feet is not adequate. Soil moisture is more than likely to be lacking on areas which previously were occupied by sod, weeds, brush, or natural tree growth, alfalfa, or any other close-growing crops.

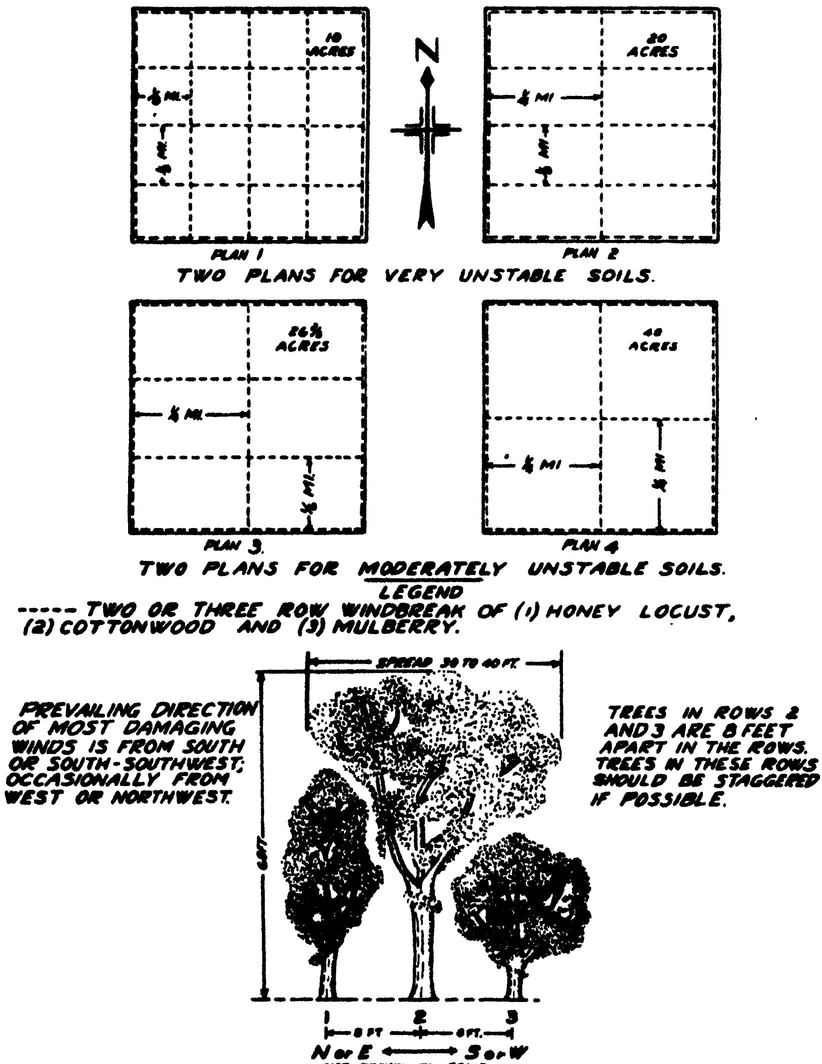

FIG. 5.—Scheme of planting windbreaks to minimize sand drifting in western Oklahoma and northwest Texas.

5. Costs of establishment can be reduced by having a carefully prepared plan, staking or marking out the area in such a manner as to have straight rows, and using sturdy, well-rooted nursery stock with a stem caliper at the ground line of ¼ inch or more. Planting stock should be grown in a latitude similar to the planting site and

should be of acclimatized native or near-native seed sources to assure adaptability to the planting site. With these precautions, the cost of the initial investment will be from $0.50 to $1.50 per acre protected. This initial investment can be justified in view of the ultimate benefits derived from the planting.

SUMMARY

1. Shelterbelt planting has been used for over 30 years as a means of reducing wind erosion on agricultural land in Greer County, Oklahoma.
2. It was found most feasible on the sandy soils, chiefly on the miles and associated series of similar texture and crop adaptability.
3. The windbreaks were generally parallel single rows of cottonwood or mulberry planted in an east-west direction at right angles to the most damaging prevailing winds.
4. Cotton responded especially well to protection of tree belts.
5. A wind erosion control program involving use of tree planting combined with strip cropping is described.
6. The design and width of shelterbelts depends on the soils and agricultural crops grown and must be varied accordingly.
7. Trees cannot be expected to live indefinitely on the Great Plains and even on the more favorable soils must be replaced at intervals of 30 to 50 years. Although some cases of regeneration from sprouts or natural seeding have been observed, it is the writer's opinion that this second crop of trees or sprouts will not attain the ultimate height or longevity of the first crop because of exhaustion of the deeply stored (6 to 25 feet) subsoil moisture by the first tree crop.
8. Shelterbelt planting is not a panacea for any and all wind erosion problems, but it certainly is feasible in those areas where trees will grow successfully and where benefits derived in crop and soil protection, wood products obtained, and increase in sales value of the farm justify the expenditure involved in planting and after-care.

ANTHESIS IN FLAX[1]

B. S. KADAM AND S. M. PATEL[2]

THE area planted to flax (*Linum usitatissimum* L.) in India is a little over 3½ million acres. Nearly 49% of this lies in the alluvial Indo-Gangetic tract in the north eastern portion of the country. Most of the remaining area is confined to what is known as the black cotton soils of peninsular India. These two tracts not only differ in the nature of the soil, but also in climatic conditions, and in both the regions flax is a cold season crop. In the alluvial tract, however, flax matures late and has a much branched and spreading habit of growth with an abundant but shallower root system. The peninsular kind is a quick-maturing type with few erect branches and a deeper root development. It has a larger grain which is richer in oil content than the alluvial type.

Flax is grown entirely for oil in India, and considerable genetic improvement of the crop has been and is being made in the important flax-growing provinces. Except for that reported by the Howards (2, 3),[3] there does not appear to be any detailed account of anthesis in flax reported in India. The studies of the Howards deal with the alluvial types exclusively. It was thought, therefore, that observations on peninsular types would be of special interest and might present some new features, besides being useful in determining a suitable technic for hybridization. The results of such observations are briefly reported in this paper.

REVIEW OF LITERATURE

The Howards (2) found that the time of blooming of flax flowers of the alluvial type is influenced more by temperature and humidity than by varietal differences. On warmer days flowers open earlier than on colder and dewy mornings. For example, on the very warm day of February 10, 1916, flowers began to show signs of opening as early as 3 a.m.; whereas on the cold day of February 9 they began to open as late as 7.30 a.m. As a rule flowers fully opened between 8.15 a.m. to 9 a.m. on a warm day and between 10 a.m. to 12 noon when the day was cold. The Howards also found that the petals were shed by the evening of the same day on which the flowers opened. A few reopened the second day, the number increasing if the day was cold or cloudy.

The flowering and pollination of European types of flax has been studied by Tammes (5) and by Fruwirth (1). The former has studied the morphology and anthesis of flax flowers in detail. According to Howard and Khan (3), Tammes observed that in Holland flowers commenced to open as early as 5 o'clock in the morning, the petals shedding by 10 to 11 a.m. Flowers rarely opened again the following morning.

[1]Contribution from the section of the Crop Botanist, Government of Bombay, Karjat, India. Published with the approval of the Director of Agriculture. Received for publication August 11, 1938.

[2]Crop Botanist and Graduate Assistant respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 940.

MATERIAL AND METHODS

Two pure lines of flax, K–5–23 and M–148–5, evolved at the Cereal Breeding Station, Kundewadi, Niphad, were chosen to study the various phases of flowering. The former is a selection from the local linseed collected from the village (Kundewadi), and the latter was obtained from a bulk sample collected from Malegaon. Both the villages are in the Nasik district. M–148–5 matures a week later than K–5–23 and has a more branching and bushy habit of growth as compared to the sparser and taller habit of growth of the other strain. Both types have blue flowers of similar size. In the evening previous to the day of making the observations, 25 buds with corollas visible were labelled. About three to four plants were required to obtain the necessary number. On one day only 16 buds were available. The strain K–5–23 was studied for seven days and M–148–5 for two days only. The records of temperature and wind movement are given in Table 1.

RESULTS

FIRST OPENING

The flax flowers began to open at 7 a.m., the process of blooming either being retarded or accelerated according to the climatic condition of the day. In Table 2 are recorded data on the frequency of fully opened flowers at half hourly intervals on different days. It will be seen that on December 17, 18, and 19, 1936, almost all the flowers in K–5–23 bloomed between 9 and 10:30 a.m. These were warm days. The temperature from 9 to 11 a.m. on December 17, 18, and 19 was between 68° to 75°, 65° to 80°, and 65° to 76° F, respectively. The minimum temperatures recorded on these days was 46°, 48°, and 46° and the maximum 84°, 84°, and 85°, respectively.

The next three days on which observations were made, December 27 and 28, 1936, and January 2, 1937, were colder days. On these days the minimum and maximum temperature recorded were 39°, 36°, and 36° and 77°, 81°, and 88°, respectively. It will be seen that on these days blooming was delayed up to 10 a.m. when the temperature reached 66°, 65°, and 71°, respectively.

January 7, 1937, was a very cold day. The minimum and maximum temperatures recorded were 33° and 84°, respectively. Unfortunately, on that day only 16 flowers were available for study and of these 5 did not bloom at all. The temperature reached 64° at 10 a.m. and progressed gradually to 71°, 73°, and 77° at 11 a.m., 12 noon, and 1 p.m., respectively. Out of 11 flowers 7 opened between 1 to 1:30 p.m. Thus on colder days there was a definite retardation in the time of blooming. If more flowers had been available for observation, most probably a greater number would have been observed to bloom before 1 p.m.

So far only the behavior of strain K–5–23 has been considered. Data on the other strain, M–148–5, are available for only two days. Here again we see (Table 2) that flowering is delayed on the cold day of December 27, 1936, while it was earlier on the December 19, a warmer day.

Compared to K–5–23, it will be seen that the flowering in this strain on the corresponding days, i.e. on December 19 and 27, 1936, was

TABLE 1.—*Hourly temperatures, relative humidity, and total wind movements for the 24 hours from 8:00 a.m. to 8:00 a.m.*

Time	Dec. 17, 1936		Dec. 18, 1936		Dec. 19, 1936		Dec. 27, 1936		Dec. 28, 1936		Jan. 2, 1937		Jan. 7, 1937	
	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %
7:00 a.m.	48°	89	50°	90	47°	90	40°	85	37°	80	37°	80	34°	84
8:00 a.m.	56°	69	55°	78	55°	74	44°	80	42°	70	43°	61	41°	65
9:00 a.m.	68°	48	65°	70	65°	65	57°	70	60°	50	55°	65	57°	40
10:00 a.m.	70°	42	72°	60	72°	64	66°	42	65°	35	71°	44	64°	38
11:00 a.m.	75°	40	80°	46	76°	50	70°	30	70°	31	80°	25	71°	28
12:00 a.m.	76°	40	81°	44	77°	52	71°	32	71°	29	82°	22	73°	26
1:00 p.m.	81°	42	82°	42	80°	47	72°	30	74°	30	85°	17	77°	21
2:00 p.m.	82°	40	83°	39	84°	43	74°	26	77°	32	86°	18	79°	21
3:00 p.m.	83°	39	84°	37	84°	31	75°	30	78°	30	87°	20	81°	20
4:00 p.m.	83°	37	82°	36	82°	30	77°	36	80°	29	86°	23	83°	26
5:00 p.m.	81°	37	80°	40	79°	27	75°	37	78°	33	84°	23	81°	30
6:00 p.m.	77°	45	75°	50	73°	41	67°	34	72°	33	78°	30	78°	25
Min. temp.	46°	—	48°	—	46°	—	39°	—	36°	—	36°	—	33°	—
Max. temp.	84°	—	84°	—	85°	—	77°	—	81°	—	88°	—	84°	—
Total wind movement in 24 hours	80		90		125		65		55		115		60	

TABLE 2.—*Time of first opening of flax flowers of two strains on various days.*

Time of full opening	Strain K 5-23							Strain M 148-5,	
	December, 1936					Jan., 1937		Dec., 1936	
	17	18	19	27	28	2	7	19	27
	Warm day	Warm day	Warm day	Cold day	Cold day	Cold day	Very cold day	Warm day	Cold day
9:01-9:30 a.m.	8	12	11	—	—	—	—	—	—
9:31-10:00 a.m.	12	11	12	1	1	1	—	8	—
10:01-10:30 a.m.	4	—	2	7	5	9	—	3	—
10:31-11:00 a.m.	—	2	—	10	5	7	—	1	7
11:01-11:30 a.m.	—	—	—	4	6	4	1	7	3
11:31-12:00 a.m.	1	—	—	3	3	3	1	1	7
12:01-12:30 p.m.	—	—	—	—	1	—	—	—	—
12:31-1:00 p.m.	—	—	—	—	3	—	—	—	1
1:01-1:30 p.m.	—	—	—	—	1	—	7	—	—
1:31-2:00 p.m.	—	—	—	—	—	—	1	—	—
2:01-2:30 p.m.	—	—	—	—	—	—	1	—	—
Not fully open	—	—	—	—	—	1	5	5	7
Total	25	25	25	25	25	25	16	25	25

later than in the former. It appears, therefore, that strain differences, at least to a certain extent, also play a part in determining the general time of blooming.

The flowers begin to close from 4:30 p.m. onwards and continue to do so up to sunset. At this period all the flowers that have bloomed during the day are found to have closed completely.

SECOND OPENING

Data on the time at which flowers reopen for the second time are presented in Table 3. It was observed that some flowers shed their petals during the act of opening. Such flowers have been classed as "Petals shed while reopening." Besides these, there were flowers which had not opened completely at the first opening and which behaved the same at the time of the second opening. Such flowers were treated separately and are classed as "Did not reopen."

The number of flowers available next day for observation varied greatly from day to day. This was mainly due to movements of wind which caused considerable incidence of shedding of petals. Thus, on December 18, 1936, 12 flowers were available for observation out of the 25 studied the previous day. This was a calm day, the total wind movement being only *80 miles*. On the next two days the afternoons were windy (total wind movement *90 and 125 miles*) and only 2 to 3 flowers out of 25 were left with petals intact.

Due to the above reasons, only very few flowers were available for observation on some of the days. It will be seen from Table 3 that the second opening was earlier than the corresponding first opening. It

will also be noted that more flowers reopened following a colder day than a warmer day, provided there had been no interference from wind.

TABLE 3.—*Time of second opening of some of the flax flowers recorded in Table 2.*

Time of full opening	Strain K 5-23							Strain Malegaon 148-5,	
	December, 1936					Jan., 1937		Dec., 1936	
	18	19	20	28	29	3	8	20	28
8:31– 9:00 a.m	5	2	—	—	—	—	—	—	..
9:01– 9:30 a.m	3	-	2	—	—	—	—	—	—
9:30–10:00 a.m	—	—	—	5	6	—	—	—	—
10:01–10:30 a.m. .	—	—	—	1	—	—	1	—	7
10:31–11:00 a.m. .	—	—	—	—	—	—	4	—	—
11:01–11:30 a.m. . . .	—	—	—	—	—	—	1	—	—
11:31–12:00 a.m.	—	—	—	—	—	—	—	—	—
Did not reopen . . .	—	—	—	—	—	1	5	4	5
Petals shed while reopening . .	4	—	1	5	5	2	2	1	1
Total.	12	2	3	11	11	3	13	5	13

PETAL SHEDDING

The flowers commenced to shed their petals the same day they opened. There was, however, very wide variation in the period a flower took to shed its petals after full opening. Flowers shed their petals within 2 hours after full opening while others were as late as 30 hours, i.e., after the second opening. Usually the shedding commenced after 12 noon and was in full swing 2 hours later. The process continued throughout the afternoon. Wind, as a mechanical agent, played an important part in hastening the shedding of petals.

In the majority of cases all five petals were shed simultaneously, while in some cases only a petal or two was shed at first. In certain flowers all the petals became loose, but remained hung up together for a period until they finally dropped down or dried up then and there. Some of the remaining flowers shed their petals the next morning.

DEHISCENCE OF ANTHERS

The time at which anthers burst was noted for 5 days in strain K–5–23 and for 1 day in strain M–148–5. The time of bursting of anthers and the time of full opening of each of the 25 flowers studied on various days are given in Table 4. It will be noted from the table that on warmer days anthers began to liberate pollen much earlier than on colder days. On very cold days the period was delayed still further. The behavior of strain M–148–5 on December 19, 1936 appeared to be more erratic than that of strain of K–5–23 on December 17 and 18, 1936. Apparently here also strain differences influenced the time of dehiscence of anthers.

It will also be seen from Table 4 that the anthers invariably dehisced before the flowers opened completely. In other words, dehiscence took place while the flower was half way open.

On colder days the interval between the time of anthers bursting and full blooming was lengthened as the petals made much slower movements to open out.

POLLINATION

The anthers begin to burst longitudinally. At this time the flower is usually in a semi-opened condition. In the case of late-opening buds and on colder days anthers burst in a number of cases much earlier and before the flower is in a semi-opened condition. At the time of bursting the anthers are away and in level with the twisted stigma. As the petals unfurl, the anthers move together and form a cap over the stigmatic surface. This insures self-fertilization very largely and takes place before the flower opens completely. In spite of such a mode of pollination, the average amount of vicinism in flax is 3% under Niphad conditions, according to Kadam, *et al.* (4).

DISCUSSION

From the foregoing evidence it will be seen that temperature plays an important part in either hastening or retarding the progress of anthesis in flax. The minimum temperature of the day exerts a greater influence in determining the time of the commencement and of the complete opening of a flax flower. If it is lower, anthesis is delayed; if higher, anthesis is hastened. On normal days during the flowering period flowers first begin to open at 7 o'clock in the morning and complete the process between 9:30 and 10 a.m. On colder days the two corresponding periods are 7:30 a.m. and 10 a.m to 12 noon. On very cold days anthesis is considerably drawn out and may continue as late as mid-afternoon.

The time of commencement and of full blooming at Niphad are later than observed by the Howards at Pusa. This is due to lower temperatures obtaining during the flowering period—December to January—at Niphad as compared to higher temperatures in February when flax is in flower at Pusa. Casual observations indicate that a more or less similar situation prevails in later maturing types at Niphad, e.g., Redwing flax of Canada, which bloom during early or mid-February.

Besides temperature, strain differences also influence anthesis to a certain extent. Differential behavior was observed between the two strains, K-5-23 and M-148-5. The latter produces a greater number of sub-branches and tertiary branching. Flower buds are larger on larger branches as compared to those produced on tertiary branches. The smaller buds are slower in their movements than larger buds so that a mixture of large and small buds in M-148-5 results in long drawn out and irregular blooming. In the case of K-5-23 there are fewer branches and sub-branches and the flower buds produced on these are more or less of similar size which results in a comparatively uniform exhibition of anthesis.

TABLE 4.—*Time of dehiscence of anthers and full opening of flowers of two strains of flax on various days.*

Bud No.	Strain K 5-23										Strain M 148-5,	
	Warm day, Dec. 17, 1936		Warm day, Dec. 18, 1936		Cold day, Dec. 28, 1936		Cold day, Jan. 2, 1937		Very cold day, Jan. 7, 1937		Warm day, Dec. 19, 1936	
	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening
	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.
1	8:37	9:23	8:25	9:42	9:45	12:24 (P.M.)	9:11	10:45	9:45	1:15 (P.M.)	9:02	11:30
2	8:25	9:28	8:20	9:05	8:49	10:50	9:10	10:25	9:33	2:00 (P.M.)	8:30	9:35
3	8:37	10:15	8:35	9.50	9:15	10:40	9:14	10:50	9:26	1:15 (P.M.)	8:35	9:35
4	8:49	10:8	8:25	9:50	8:45	10:30	9:13	10:10	9:15	12:00	8:40	9:45
5	8:50	9:44	8:35	9:28	9:24	11:10	9:02	10:15	9:50	—*	8:50	11:15
6	8:26	9:31	8:26	9:25	8:45	10:00	9:05	10:05	10:05	—*	8:45	10:02
7	8:26	9:10	8:26	9:42	9:15	10:52	9:15	10:55	9:20	1:15 (P.M.)	8:52	11:15
8	8:27	9:22	8:27	9:27	9:11	10:30	9:18	11:45	9:51	—*	8:41	9:45
9	8:39	9:11	8:27	10:45	9:27	11:36	9:35	11:45	9:46	—*	10:10	—*
10	8:28	9:34	8:28	9:40	9:27	1:30 (P.M.)	9:05	10:15	9:37	2:30 (P.M.)	8:41	9:36
11	8:33	9:37	8:28	9:38	8:50	10:30	9:00	9:55	10:04	—*	8:51	10:45
12	8:50	10:06	8:28	9:05	9:05	10:30	9:08	10:25	9:37	1:15 (P.M.)	8:46	10:15
13	8:51	9:54	8:20	9:05	9:06	10:40	10:20	—*	9:15	11:20	8:56	11:15
14	8:35	9:30	8:20	9:30	9:22	12:31 (P.M.)	9:18	10:35	9:34	1:15 (P.M.)	8:55	11:30

15	8:29	9:45	8:27	9:05	9:21	11:25	9:33	11:15	9:40	1:15 (P.M.)	8:57	11:15
16	8:50	9:38	8:29	9:17	9:14	11:05	9:30	11:15	9:34	1:15 (P.M.)	8:52	10:07
17	8:40	9:29	8:31	9:56	9:20	11:38	9:30	11:45	—	—	9:20	—*
18	9:18	12:00	8:30	9:39	9:02	10:49	9:33	10:45	—	—	8:42	9:41
19	8:41	9:50	8:30	9:40	9:00	10:30	9:27	10:45	—	—	9:17	—*
20	8:20	9:39	8:30	9:41	9:23	11:10	9:32	10:35	—	—	9:05	12:00
21	8:25	10:16	8:30	9:27	9:26	1:00 (P.M.)	9:20	10:15	—	—	8:43	9:41
22	8:13	9:42	8:30	11:00	9:25	1:00 (P.M.)	9:20	10:25	—	—	9:00	11:15
23	8:30	9:46	8:31	9:24	9:15	11:05	9:34	11:10	—	—	9:20	—*
24	8:30	9:43	8:31	9:55	9:25	11:45	9:27	11:10	—	—	8:44	9:55
25	8:30	9:24	8:31	9:25	9:25	11:10	9:10	10:10	—	—	9:45	—*

*Did not fully open.

Irrespective of the climatic condition of the day, anthers invariably burst before the flowers fully bloom. This behavior enables emasculation of flowers for hybridization in early morning. The safest time to emasculate is between 7 and 7:30 a.m. Flowers emasculated at this period and protected from pollination have been found to set no capsules. Emasculation is done by pulling off the corolla with a swift jerk by means of forceps. The anthers are removed subsequently and pollination done 2 hours later.

SUMMARY

1. Under Niphad conditions flax flowers normally commence to open at 7 a.m. and opening is completed by 10 to 10:30 a.m. If the days are cold the process is delayed and may go on up to as late as 2:30 p.m. The minimum temperature of the day influences both time of beginning and full opening of a flower.

2. Flax flowers reopen the next day to a varying extent and the second opening is earlier than the first.

3. Petals may be shed as soon as 2 hours after full opening or may be delayed 30 hours, i.e., until after the second opening.

4. Dehiscence of anthers invariably precedes the full opening of the flowers.

5. There are indications that strain differences may also exist in the period of modal blooming in flax.

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THE RELATION BETWEEN LEAF TISSUE PIGMENT CONCENTRATION AND YIELD IN CORN[1]

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As pointed out by Spoehr (4),[3] the physiological processes associated with the synthesis of dry matter in plants have been investigated in detail. The application of the knowledge gained from these studies to plant breeding research should provide an opportunity to further evaluate the extent to which variations in physiological properties are associated with such factors as yielding ability. Since chlorophyll is an essential factor in the photosynthetic system, a further study of the relation between the concentration of chlorophyll and yielding ability within various strains of crop plants may furnish data which would aid in the selection of superior strains.

Sprague and Curtis (5) have studied the correlation between the amount of chlorophyll per 100 sq. cm. of leaf area and total chlorophyll per plant to the yield of shelled grain and total dry matter in corn. In general, these investigators obtained correlation coefficients that were positive, but because of the small numbers of inbred strains and crosses used several of the coefficients are too low to be statistically significant when interpreted on the basis of Fisher's (1) levels of significance for small numbers. Therefore, it seemed desirable to make a further study of these relationships with several groups of material available in the corn improvement program.

EXPERIMENTAL METHODS

In the study begun in 1936, a group of yellow endosperm crosses and their parental inbred lines were grown at the Waseca Branch Station in single row plats 10 hills long. The yields of the single crosses had been previously determined in a replicated yield trial conducted in 1934–35. Leaf tissue samples for pigment determinations were collected approximately three weeks after the silking stage. Five 1-sq. cm. areas were removed with a leaf punch from the ear leaf of five plants, placed in a small vial, and immediately frozen with "dry ice." A similar number of samples were obtained from the same leaves and preserved in acetone. The acetone-preserved and frozen samples were then stored three months in the dark at −15° C. until analyzed.

During 1937 a large number of Golden Bantam single crosses were grown in replicated trials. The crosses employed in this study were selected for analysis on the basis of the chlorophyll percentage of the inbred lines made in single plat trials in 1936 and in each of two series of plats grown in 1937. From 16 inbred lines analyzed for total chlorophyll and carotenoids, four were classified as high and four as low in total chlorophyll. The difference between the high and low

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[3]Figures in parenthesis refer to "Literature Cited", p. 946.

chlorophyll inbred lines was statistically significant. Twenty-eight single crosses representing all combinations of high × high, high × low, and low × low chlorophyll inbred lines were studied for total chlorophyll and total carotenoids concentration in each of two field replications.

Pigment studies were also made on a group of 36 yellow dent inbred lines used in hybrid combinations in the corn improvement program. These yellow dent lines were grown in two field replications and leaf tissue samples from these were collected for analysis.

In all of the material sampled in 1937, five 1-sq. cm. areas were removed from the ear leaf of each of five plants and immediately frozen in a stoppered vial by "dry ice." Previous studies by Sprague and Curtis (5) showed that the chlorophyll content of the ear leaf furnished a reliable index of the amount found in the leaves of the entire plant. The Golden Bantam inbred lines were analyzed the day following collection to enable the proper selection of single crosses. The single crosses and field corn inbred lines were stored in the dark at −15° C until analyzed 4 to 5 months later.

The frozen leaf samples for pigment analysis were weighed, then triturated with sand in a mortar. After the pigments were extracted with acetone for 1 hour in a Goldfisch extractor, the acetone solution of pigments was transferred to a separatory funnel containing 25 to 30 cc of diethyl ether. The acetone in the solution was removed by several washings with water. The percentage of chlorophyll A and B and total carotenoids was determined (in ether) spectrophotometrically.

EXPERIMENTAL RESULTS

METHODS OF PRESERVING LEAF SAMPLES

Since no adequate studies had been made concerning the best method of preserving leaf tissue samples for chlorophyll determinations, samples frozen in the field as well as those preserved in acetone were analyzed for chlorophyll A and B. Because the samples for the frozen and acetone series had been collected from the same leaves, it was possible to treat the two methods of preservation on the different crosses as a series of paired comparisons. The analytical data obtained were studied by means of the analysis of variance to determine the significance of the difference between the two methods and by means of correlation coefficients to determine the relationship between the values obtained. The results of this study with 53 paired samples are presented in Table 1.

TABLE 1.—*Relation between the percentage of total chlorophyll and the ratio of chlorophyll A to B from 53 samples of frozen and acetone-preserved corn leaf tissue.*

Characters analyzed	Frozen tissue	Acetone preserved tissue	Difference	F
Percentage total chlorophyll....	0.349	0.370	0.021	9.41*
Ratio of chlorophyll A to B...	3.88	4.15	0.27	12.11*

*Exceeds the 1% point in level of significance.

Although the differences in percentage of total chlorophyll and the ratio of chlorophyll A to B by the two methods of preservation were relatively small, the consistency of these differences among the samples gave a significant value for F. A correlation coefficient of +0.638

was obtained for total chlorophyll and +0.752 for the ratio of chlorophyll A to B by the two methods employed. Both of the coefficients exceed the 1% point in level of significance and indicate a consistant relationship between the analytical results for the two methods of preservation.

The authors selected the freezing method as being superior to the acetone method of preservation because after 90 to 150 days storage extracts of the frozen tissues spectroscopically were more like those extracts obtained from fresh tissues (extracted immediately after collection). Apparently the small difference observed in the two methods of preservation is due to oxidation of the chlorophylls. The acetone-preserved samples showed a consistently higher absorption at wave length 6700 A than the frozen samples. Recently, McKinney (3) has pointed out the possible changes occurring in leaf tissues when subjected to different methods of killing the cells. His data for tobacco indicate that freezing technic is satisfactory for killing leaf tissues.

RELATION BETWEEN CHLOROPHYLL AND CAROTENOID PIGMENTS AMONG INBRED LINES AND F_1 CROSSES

In the study of leaf pigments of sweet corn, analyses were made for total cholorophyll and total carotenoid pigments of inbred lines and their single crosses. The inbred lines and single crosses differed significantly in percentage of total chlorophyll and total carotenoids as measured by the analysis of variance from duplicate plats This provided an opportunity to study the correlation between the percentage of total chlorophyll and total carotenoids of the inbred lines and their single crosses. A summary of these corrleation coefficients is presented in Table 2.

TABLE 2.– *Correlation between total chlorophyll and total carotenoids of parents and single crosses.*

Characters correlated	Correlation coefficients	
	Total chlorophyll	Total carotenoids
High parent and F_1 crosses	0.5745	0.3452
Low parent and F_1 crosses	0 6102	0.4895
Average of both parents and F_1 crosses	0.7032	0.4893

Level of significance for 5% point = 0 3809
Level of significance for 1% point = 0.4869

From the data in Table 2 it is evident that there is a significant correlation between total chlorophyll and total carotenoids in the inbred lines and their F_1 crosses. For total chlorophyll all of the correlation coefficients between the parents and their F_1 crosses exceed the 1% point in level of significance. For total carotenoids, the correlations between the low parent and average of both parents with the F_1 crosses exceed the 1% point, while the relation between the high parent used and the F_1 crosses was somewhat below the 5% point in level of significance. These results indicate the extent to which, under the conditions of the experiment, total chlorophyll and carotenoid development were dependent upon inheritance.

Evidence was obtained also that the percentage of total chlorophyll in the F_1 crosses consistently exceeded the average of the two parents, indicating a possible heterosis for the chlorophyll pigments. The average percentage of total chlorophyll and total carotenoid pigments of the inbred lines and their single crosses is given in Table 3.

TABLE 3.—*Average percentage of total chlorophyll and total carotenoid pigments of inbred lines and single crosses of Golden Bantam sweet corn.*

Chlorophyll or carotenoid pigments of inbred parents	No. of crosses	% chlorophyll		% carotene	
		F_1 cross	Ave. of parents	F_1 cross	Ave. of parents
High×High	6	0.431	0.375	0.0680	0.0379
High×Low.	16	0.379	0.331	0.0567	0.0337
Low×Low	6	0.335	0.288	0.0542	0.0293

RELATION BETWEEN TOTAL CHLOROPHYLL CONCENTRATION AND YIELDS

Since the relationship between chlorophyll concentration and yield is of importance to both the plant breeder and plant physiologist, a study was undertaken with several groups of material to determine the extent to which variation in total chlorophyll was coincident with variation in yield. In this study a group of single crosses in dent corn, a group of single crosses of Golden Bantam sweet corn, and two groups of inbred lines were investigated. A summary of the data obtained, together with a study of the relation between total chlorophyll and total carotenoid pigments, is given in Table 4.

From the results presented in Table 4 it becomes evident that there is very little association between total chlorophyll (green weight basis) and yielding ability of corn. These data are in agreement with those reported by Jenkins (2) who obtained correlation coefficients of −0.07 and −0.11 between chlorophyll grade (concentration) of parents and yield of crosses for 1926 and 1927, respectively. Likewise, he obtained a correlation coefficient of −0.21 between chlorophyll grade and yield of inbred lines.

The evidence presented in Table 4 does not confirm the data reported by Sprague and Curtis (5), who obtained the following correlation coefficients: For the inbred lines (12 strains) $+.55\pm.14$ between shelled grain per plant and chlorophyll per 100 sq. cm. of leaf blade and $.46\pm.15$ for chlorophyll per plant and total yield; for F_1 crosses (18 strains) $+.25\pm15$ between shelled grain per plant and chlorophyll per 100 sq. cm. of leaf blade and $+.36\pm14$ between chlorophyll content and yield of shelled corn.

In the field corn single crosses used in this study, 43 hybrids varied from 0.287 to 0.475% chlorophyll and the yields from these same crosses varied from 87 to 127% of the check varieties employed, indicating widely different values for both total chlorophyll and yield. A correlation coefficient of −0.328 does not approach the 5% point in level of significance and indicates that variations in yield are not related to variations in total chlorophyll. The writers wish to point out

that these yields are for the average of 1934 and 1935 and that the chlorophyll data is for a single plat grown in 1936.

TABLE 4.—*Correlation between chlorophyll and yield within single crosses of inbred lines of corn and between total chlorophyll and total carotenoid pigments.*

Characters correlated	Material studied	Year	N	Correlation coefficient
In Single Crosses				
Per cent total chlorophyll and per cent total carotenoids	Sweet corn	1937	28	.754†
Per cent total chlorophyll and per cent total carotenoids	Field corn	1936	43	.337*
Per cent total chlorophyll and yield	Sweet corn	1937	28	−.065
Per cent total chlorophyll and yield	Field corn	1936	35	−.328
In Inbred Lines				
Per cent total chlorophyll and per cent total carotenoids	Sweet corn	1937	16	.838†
Per cent total chlorophyll and per cent total carotenoids	Field corn	1937	36	.853†
Per cent total chlorophyll and yield	Sweet corn	1937	16	.105
Per cent total chlorophyll and yield	Field corn	1937	36	.147
Per cent total chlorophyll and top cross yield	Field corn	1937	36	−.203
Mgm. total chlorophyll in ear leaf and yield	Field corn	1937	36	.106
Mgm. total chlorophyll per sq. cm. leaf and leaf area	Field corn	1937	36	−.195
Per cent total chlorophyll 1936 and 1937	Sweet corn	——	16	.642†

*Exceeds the 5% point in level of significance.
†Exceeds the 1% point in level of significance.

In a group of Golden Bantam single crosses, total chlorophyll determinations and yield were made in the same series of plats. In this study the crosses showed significant variation in percentage of chlorophyll concentration, and the single crosses approached the 5% point in level of significance for variation in yield. In this group the correlation coefficient was −0.065.

In the studies involving total chlorophyll and yield with inbred lines of sweet corn, a correlation coefficient of +0.105 was obtained with a group of 16 inbred lines, whereas a coefficient of +0.147 was found for 36 inbred lines of field corn. Neither one of these coefficients is significant. Since the above coefficients are between total chlorophyll and yield, a study was made on 36 lines of field corn to determine the relationship between the mgm. of chlorophyll in the ear leaf and yield. The coefficient obtained was +0.106 and likewise is not significant. Finally, a study was made to determine the relation between total chlorophyll of 36 inbred lines and their combining ability as measured by top cross yields conducted in four replicated trials. The coefficient obtained, −.203, is also below the 5% point in level of significance.

Since none of the correlation coefficients between chlorophyll and yield are statistically significant in any of the groups of material studied, it would appear that variations in chlorophyll concentration

do not have an important effect on yield in corn. These results would therefore suggest that the quantities of chlorophyll found in normal green corn plants are more than sufficient and that chlorophyll is not a limiting factor in the development of yield in corn. In fact, the quantities of chlorophyll may be in excess of the normal needs since variegated plants having nearly 50% of the leaf tissue devoid of chlorophyll are seemingly nearly as vigorous as normal green plants.

In all groups of material studied, a significant correlation was obtained between the percentage of total chlorophyll and the percentage of total carotenoids. Evidently those physiological processes that result in the formation of chlorophyll pigments are closely related to those which result in the development of carotenoid pigments.

SUMMARY

1. A comparison was made between the freezing and acetone methods for preserving leaf tissues for pigment analysis. Spectrophotometrically, the least amount of decomposition occurred in the frozen series, although the discrepancy between the two methods is very slight.

2. Evidence was obtained that a very marked relationship exists between total chlorophyll and total carotenoids in the parental inbred lines and in their F_1 crosses.

3. Analytical data show that the percentage of total chlorophyll in the F_1 crosses exceeded the average of the two parents, indicating possible heterosis for the chlorophyll pigments.

4. In the study with several groups of material to determine the relation between total chlorophyll concentration in the leaf tissue and yield in corn, it was found that the correlation coefficients were less than required to attain the 5% point in level of significance.

5. A highly significant positive correlation was obtained between the percentage of total chlorophyll and total carotenoids in corn leaf tissue.

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UNBALANCED ARRANGEMENTS OF PLATS IN LATIN SQUARES[1]

S. C. SALMON[2]

A STRICT use of random arrangement of plats in Latin squares usually results in an unbalanced distribution of the plats of one or more of the treatments. A striking example are diagonal squares in which all plats of a treatment fall in a straight line on one of the principal diagonals, those of the other treatments falling on secondary diagonals or in various ways. In this paper the term diagonal square is used to designate those in which all plats of a treatment fall on one of the principal diagonals irrespective of the arrangement of the plats of the remaining treatments.

Practical agronomists and statisticians will no doubt generally agree that such arrangements are unsatisfactory. Tedin[3] and Fisher[4] have indicated or implied agreement with this viewpoint. Observations suggest that the objections to them would be almost, though perhaps not quite, so great as having all plats of a given variety or treatment in a single row or column. The use of local control or the usual row and column restrictions in otherwise random Latin squares were devised in part to avoid the latter contingency. The frequency with which diagonal squares occur would therefore seem to be of some consequence.

Fig 1 is a 4×4 Latin square with the usual row and column re-

	1	2	3	4
1	A	C	D	B
2	C	A	B	D
3	B	D	A	C
4	D	B	C	A

FIG. 1.—A diagonal Latin square.

strictions. A, B, C, and D are varieties or treatments to be compared. All four plats of variety or treatment A fall on one of the principal

[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication August 24, 1938.

[2]Principal Agronomist.

[3]TEDIN, OLAF. The influence of systematic plot arrangement upon the estimate of error in field experiments. Jour. Agr. Sci., 21:191–208. 1931.

[4]FISHER, R. A. The Design of Experiments. London: Oliver and Boyd. 1935. (Pages 85 to 90.)

diagonals. The question to be answered is how frequently may such an arrangement, with respect to A alone, be expected as a result of chance.

Considering first row 1, it will be apparent that in order to have the particular diagonal square illustrated in Fig. 1, A must fall in column 1. Since there are four plats in the row the probabilities of its doing so are obviously one-fourth. In row 2, A is excluded from column 1, because otherwise there would be two plats of A in that column. Since it may fall in any one of the three plats that are left, the probability of its falling in column 2 is one-third. In row 3, A is excluded from columns 1 and 2, there are two left, and consequently the probability of its falling in column 3 is one-half. With the positions of A thus determined for the first, second, and third rows, the fourth plat must fall in column 4 of row 4. The probability is, therefore, certainty or one.

The probabilities of all four plats of A falling on the principal diagonal represented in figure 1 is $\frac{1}{4}\cdot\frac{1}{3}\cdot\frac{1}{2}\cdot\frac{1}{} = \frac{1}{24}\cdot$ That is, all four plats of the A variety or treatment would be expected to fall as indicated once in 24 Latin squares. But there are two diagonals and four varieties or treatments. Hence the probability of all four plats of any one variety or treatment falling on one or the other of the two principal diagonals is $\frac{1}{24}\cdot\frac{2}{}\cdot\frac{4}{} = \frac{1}{3}$. If the result is surprising to those who have not considered the matter, it can easily be verified by empirical trials, or in some cases by observing Latin square experiments actually in use.

It will now be instructive to determine the probability of a similar occurrence in a 4×4 Latin square without the row and column restrictions, i.e., one in which all plats are distributed at random with no restrictions whatever. In this case the possibility of all plats occurring in any row or column as well as on the diagonals must be considered.

In a manner similar to that above, it can be shown that the probability of all four plats of A falling in a designated row, column, or principal diagonal is $\frac{4}{16}\cdot\frac{3}{15}\cdot\frac{2}{14}\cdot\frac{1}{13} = \frac{1}{1820}$; and the probability of all four plats of any variety or treatment falling in a like manner, i.e., the probability of getting four plats of any variety or treatment in a straight line whether this be in rows, columns, or diagonals, is $\frac{1}{1820}\cdot\frac{4\,(4+4+2)}{} = \frac{40}{1820} =$ approximately $\frac{1}{45}\cdot$

This means that in a 4×4 Latin square the chances of getting all four plats of any variety or treatment in a striaght line are 15 times as great with restricted as with unrestricted random distribution. It thus appears that the imposition of row and column restrictions on otherwise random Latin squares not only fails to accomplish one of the purposes for which they were intended but actually increases to a very considerable degree the tendency toward unbalanced distributions in so far as these are measured by the frequency of those in which all plats of a variable occur in a straight line.

There are, of course, other unbalanced and undesirable arrangements. Thus, two plats may fall on a principal diagonal and the remaining plats next to the principal diagonal. In a restricted Latin square the probabability of such an occurrence is twice that for all plats on a diagonal .Or all plats but one, or a majority of all plats, may fall on or on one side of a diagonal.

The probability of having all plats in a straight line decreases as the size of the Latin squares increases, but the proportion of cases in which such an arrangement is obtained in restricted as compared with unrestricted random arrangements increases as the size of the Latin squares increases. Thus, in a 5×5 Latin square the respective probabilities for restricted and unrestricted arrangements are approximately 1/12 and 1/886. The corresponding probabilities for a 6×6 Latin square are 1/60 and 1/23188. Hence, the ratios in restricted arrangements to those in unrestricted arrangements are approximately 15 to 1, 74 to 1, and 386 to 1 in 4×4, 5×5, and 6×6 Latin squares, respectively. A critical study of other unbalanced arrangements has not been made.

The undesirable effects of unbalanced arrangements are particularly serious in experiments in which permanent plats are required, such as with alfalfa or grass, fruit or forest trees, and certain soil experiments. In these an unbalanced arrangement will introduce systematic errors which will persist during the life of the experiment. It should require no extensive discussion to prove that dependence on restricted random arrangements in such experiments is likely to lead to real and serious errors.

The above is presented not in support of unrestricted random arrangements, but merely to point out that some of the supposed advantages of restricted random arrangements are not realized in practice. Student[5] recently has presented what appear to be convincing arguments for balanced systematic arrangement of plats. Among other things he emphasizes that improvement in the estimate of random error brought about by the substitution of a restricted random arrangement for balanced systematic arrangements is secured only at the expense of the accuracy of the experiment itself. The facts presented herein would seem to support that point of view.

Certainly agronomists are or should be more concerned with the accuracy and reliability of an experiment than with the accuracy of the estimate of random error. Perhaps it is worth while to remember that, whereas the theoretical arguments for randomization have been developed on the assumption of large numbers, i.e., large numbers of plats or of experiments repeated a large number of times, the agronomist often finds himself obliged to base conclusions on specific experiments in which each variable is repeated only a very small number of times. This means not only that the results of an experiment are subject to some uncertainty but also that the estimate of random error is only an approximation. Indeed it is doubtful whether a statistically significant difference between estimates of error for restricted random arrangements as compared with systematic arrangements can

[5]Student. Comparison between balanced and random arrangements of field plots. Biometrika, 29:363–379. 1938.

be demonstrated for most field experiments. Also field experiments are necessarily of limited duration and they are not repeated on every farm. Often the utilization of their results depends on economic factors which also vary from time to time and from place to place. The net result is that any practical deductions derived from such experiments are subject to rather large errors of personal judgment. A difference in experimental results so small as to bring into question the reliability of the estimate of random error depending on plat arrangement is not likely to be of any importance at all. Why then be too much concerned about the estimate of random error? It is important, however, to know that all possible precautions have been taken to assure reliable experimental results.

CARBOHYDRATES OF THE COTTON PLANT UNDER DIFFERENT SEASONAL CONDITIONS AND FERTILIZER TREATMENT[1]

D. R. Ergle, L. E. Hessler, and J. E. Adams[2]

SEVERAL workers in the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, have studied the effects of fertilizers on the composition of the cotton plant (2, 3, 4, 6),[3] as a part of a broad program for the investigation of fertility factors associated with the occurrence of cotton root-rot. It has been found in field studies on soils of the Wilson series (5) that nitrogen and fertilizers having a high nitrogen content decrease the number of cotton plants killed by the fungus *Phymatotrichum omnivorum* (Shear) Duggar, while phosphate and fertilizers having a high phosphoric acid content increase the mortality. Results of studies of the carbohydrate content of the tops and roots of cotton plants grown on Wilson clay loam in Texas have been given (3). The concentration of total sugars in the roots was greater than in the tops for the growth period as a whole. The diose sugars were greater than the monose sugars in the roots. During the latter stages of boll formation the monose sugars were greater than the diose sugars in the tops. Total sugars decreased in concentration in the plant tops between the seedling stage and square formation but increased during boll formation.

Complete fertilizers produced plants with a higher level of soluble and insoluble carbohydrates in tops and roots in the latter stages of plant development. Nitrogen alone had but little effect, but phosphorus alone produced plants containing more soluble and insoluble carbohydrates in the tops. The greater carbohydrate content of the plants correlated with larger plant growth and larger yields of cotton. Fertilizer mixtures that produced plants with the greatest total carbohydrate content were the mixtures that produced largest plant growth and greatest yields.

PLAN OF EXPERIMENT

The plat arrangement, sampling technic, and methods of analysis used in previous studies (3) were followed in 1936. One series of plats was located on Wilson fine sandy loam, in Hunt County, and the other on Houston black clay, in Travis County, Texas. The Houston soils, comprising about 80% of the Blackland prairie section, are calcareous, while the normal Wilson soils are non-calcareous in the upper layers (1).

Composite samples of whole cotton plants (tops and roots) were obtained from field plats[4] used to determine the effect of fertilizer on the maturity and yield of

[1]Contribution from the Division of Soil Fertility Investigations, Bureau o Plant Industry, U. S. Dept. of Agriculture. Received for publication August 25, 1938.

[2]Assistant chemists and Soil Technologist in Charge of the Soil Fertility Cotton Root-Rot Investigations at Austin, Texas, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 959.

[4]Acknowledgment is made to Messrs. H. V. Jordan, J. H. Hunter, P. M. Jenkins, and H. A. Nelson for the care of the plats and assistance in the collection of the samples.

cotton and the incidence of root-rot. The fertilizers used were as follows: 15-0-0, 9-3-3, 0-15-0, and 3-9-3.[5] Unfertilized plats served as checks. The fertilizer was applied at the rate of 900 pounds per acre simultaneously with the planting of the experiment to cotton.

The Wilson fine sandy loam area, designated as field C, was under drought conditions from the latter part of July to the end of the season. Premature opening of some bolls made sampling objectionable after August 11. In contrast, field D, a Houston black clay soil, received normal rainfall; however, sampling was discontinued August 10.

Records were made at weekly intervals of the morphological changes in the plants of both fields. These data have been reported in detail (5).

Approximate dates pertinent to this work are as follows:

Observations	Field C	Field D
	Wilson soil	Houston soil
Cotton up to a stand	May 4	Apr. 28
Seedling stage	June 16	June 2
Squares appearing	June 16	June 2
Bolls appearing	July 7	June 29
Light boll set	July 13	July 13
Heavy boll set	July 27	July 27
Bolls opening	Aug. 11	Aug. 3
Cotton picked	Aug. 19	Aug. 27

RESULTS

The data from the Wilson fine sandy loam (field C) are given as Table 1 and those for the Houston black clay (field D) as Table 2. These are on the basis of green material.

The effects of fertilizer treatment on plant composition as found for top and root parts (3) are reduced when the whole cotton plant is used for analysis. There is indicated, however, some fertilizer effect on plants from the Wilson soil and, to a less extent, on those from the Houston. The whole plant is a farily good indicator of the variations in carbohydrate concentration of cotton plants at different growth periods.

Seasonal changes in concentrations of carbohydrates for plants grown in unfertilized plats on Houston and Wilson soils are illustrated graphically in Fig. 1. The similarity of the two sets of graphs with respect to the indicated stages of development suggest that certain changes are inherent in the plant and that the influence of the soil type is not paramount. Even the effects of fertilizers are not sufficient to alter materially the trends in concentrations during certain morphological changes. The concentration levels may be influenced, but the direction of change will likely remain unaffected. In general the results from the unfertilized plants, as illustrated in Fig. 1, as well as those from the fertilized plants in Tables 1 and 2, show that the appearance of squares is attended by decreased concentrations of

[5]Fertilizer ratios are given in the order $N-P_2O_5-K_2O$. One-half of the nitrogen was derived from sulfate of ammonia and one-half from nitrate of soda; the phosphoric acid was from 18% superphosphate; and the potash from sulfate of potash.

TABLE 1.—*Carbohydrates of cotton plants grown on Wilson fine sandy loam, field C, Caddo Mills, Texas, as influenced by fertilizer treatment and stage of growth, 1936.**

Date, 1936	Monosaccharides %	Disaccharides %	Total sugars %	Polysaccharides %	Total carbohydrates %	Weight per plant, grams	Moisture green material %
			Fertilizer 0–15–0				
May 19	0.37	0.09	0.46	2.33	2.79	2.53	85.3
June 2	0.32	0.33	0.65	2.75	3.40	9.42	78.6
June 9	0.42	0.55	0.97	3.13	4.10	17.50	78.8
June 16	0.60	0.93	1.53	4.42	5.95	24.50	73.9
June 23	0.68	0.78	1.46	4.39	5.85	38.00	73.5
June 30	—	—	—	—	—	51.10	70.9
July 14	1.11	0.95	2.06	5.07	7.13	75.70	73.7
July 28	1.20	1.23	2.43	7.48	9.91	108.00	66.8
Aug. 11	0.68	1.02	1.70	10.19	11.89	184.00	51.6
Average	0.67	0.74	1.41	4.97	6.38	56.75	72.5
			Fertilizer 3–9–3				
May 19	0.34	0.20	0.54	2.57	3.11	2.57	84.3
June 2	0.32	0.32	0.64	2.60	3.24	10.20	81.2
June 9	0.44	0.60	1.04	3.36	4.40	18.90	79.1
June 16	0.59	0.82	1.41	3.89	5.30	25.30	76.4
June 23	0.67	0.79	1.46	4.42	5.88	41.80	73.4
June 30	0.73	0.83	1.56	5.35	6.91	55.00	70.9
July 14	0.94	1.00	1.94	4.95	6.89	96.80	72.0
July 28	0.95	1.00	1.95	6.15	8.10	125.00	67.5
Aug. 11	0.74	1.08	1.82	9.52	11.34	185.00	53.3
Average	0.64	0.74	1.37	4.76	6.13	62.29	73.1
			Fertilizer 9–3–3				
May 19	0.32	0.19	0.51	3.02	3.53	1.97	83.1
June 2	0.35	0.28	0.63	3.54	4.17	5.97	77.8
June 9	0.47	0.53	1.00	3.39	4.39	12.10	79.2
June 16	0.62	0.91	1.53	4.04	5.57	20.30	74.9
June 23	0.60	0.73	1.33	4.12	5.45	33.30	75.1
June 30	0.69	1.01	1.70	5.29	6.99	52.50	71.9
July 14	0.89	0.95	1.84	4.64	6.48	83.20	73.3
July 28	1.17	1.14	2.31	6.92	9.23	129.00	67.5
Aug. 11	0.93	0.89	1.82	9.43	11.25	192.00	55.5
Average	0.67	0.74	1.41	4.93	6.34	58.93	73.1
			Fertilizer 15–0–0				
May 19	0.28	0.25	0.53	3.30	3.83	1.61	82.6
June 2	0.33	0.34	0.67	3.13	3.80	2.75	77.2
June 9	0.44	0.67	1.11	3.86	4.97	5.04	76.8
June 16	0.53	0.74	1.27	4.98	6.25	9.30	74.3
June 23	0.49	0.74	1.23	4.47	5.70	17.00	74.0
June 30	0.53	0.68	1.21	4.91	6.12	29.40	74.3
July 14	0.64	0.75	1.39	4.09	5.48	48.40	73.6
July 28	1.06	1.23	2.29	7.38	9.67	83.30	65.8
Aug. 11	0.62	1.14	1.76	10.36	12.12	195.00	55.1
Average	0.55	0.73	1.27	5.16	6.44	43.53	72.6

*All data expressed on green weight basis.

TABLE 1.—*Concluded.*

Date, 1936	Mono-saccharides %	Disaccharides %	Total sugars %	Poly-saccharides %	Total carbohydrates %	Weight per plant, grams	Moisture green material %
			No fertilizer				
May 19	0.37	0.30	0.67	3.91	4.58	1.78	82.0
June 2	0.34	0.35	0.69	3.13	3.82	3.08	77.6
June 9	0.40	0.64	1.04	3.78	4.82	6.70	78.4
June 16	0.50	0.91	1.41	4.85	6.26	10 80	72.8
June 23	0.46	0.72	1.18	4.39	5.57	13.40	73.7
June 30	0.58	0.87	1.45	5.38	6.83	27.10	70.9
July 14	0.64	0.74	1.38	4.58	5 96	39.40	74.3
July 28	1.06	1.21	2 27	7.28	9.55	53.00	68.4
Aug. 11	0.72	1.18	1.90	10 20	12.10	196.00	57.2
Average	0.56	0.77	1.33	5.28	6.61	39 03	72.8

TABLE 2.—*Carbohydrates of cotton plants grown on Houston black clay soil (field D), Pflugerville, Texas, as influenced by fertilizer treatment and stage of growth, 1936.**

Date, 1936	Mono-saccharides %	Disaccharides %	Total sugars %	Poly-saccharides %	Total carbohydrates %	Weight per plant, grams	Moisture green material %
			Fertilizer 0-15-0				
May 4	0.68	0.19	0.87	3.03	3.90	1 30	83.4
May 11	0.39	0.10	0.49	3.41	3.90	2.50	84.7
May 18	0.45	0.19	0.64	—	—	5.10	81.9
June 1	—	—	0.75	5.14	5.89	8.76	76.1
June 8	0.43	0.09	0.52	3.17	3.69	17.10	78.9
June 15	0.65	0.31	0.96	3.88	4.84	31.40	77.3
June 29	0.74	0.17	0.91	4.58	5.49	64.30	73.1
July 13	0.32	0.31	0.63	5.07	5.70	137.00	75.0
July 27	0.83	0.29	1.12	6.47	7.59	212.00	72.0
Aug. 10	1.14	0.54	1.68	8.03	9.71	197.00	65.4
Average	0.63	0.24	0.86	4.75	5.63	67.65	76.8
			Fertilizer 3-9-3				
May 4	0.54	0.35	0.89	3.39	4.28	1.31	81.8
May 11	0.38	0.12	0.50	3.62	4.12	2.70	83.9
May 18	0.36	0.25	0.61	—	—	5.38	82.5
June 1	0.57	0.11	0.68	4.53	5.21	9.04	79.0
June 8	0.29	0.28	0.57	2.93	3.50	20.80	80.6
June 15	0.57	0.36	0.93	3.85	4.78	38.00	77.2
June 29	0.70	0.33	1.03	4.04	5.07	96.30	73.8
July 13	0.29	0.24	0.53	4.51	5.04	203.00	72.8
July 27	0.70	0.35	1.05	5.28	6.33	303.00	72.5
Aug. 10	1.07	0.88	1.95	8.23	10.18	303.00	62.6
Average	0.55	0.33	0.87	4.49	5.39	98.26	76.7

*All data presented on green weight basis.

TABLE 2.—*Concluded.*

Date, 1936	Monosaccharides %	Disaccharides %	Total sugars %	Polysaccharides %	Total carbohydrates %	Weight per plant, grams	Moisture green material %
			Fertilizer 9-3-3				
May 4	0.54	0.44	0.98	3.21	4.19	1.30	81.1
May 11	0.40	0.11	0.51	3.85	4.36	2.38	82.5
May 18	0.36	0.31	0.67	—	—	4.61	81.3
June 1	0.61	0.22	0.83	5.80	6.63	6.83	76.1
June 8	0.46	0.00	0.45	2.97	3.42	14.40	80.3
June 15	0.71	0.17	0.88	3.67	4.55	25.20	77.3
June 29	0.61	0.26	0.87	4.24	5.11	86.20	73.6
July 13	0.24	0.30	0.54	4.14	4.68	167.00	74.7
July 27	0.59	0.54	1.13	4.73	5.86	280.00	73.5
Aug. 10	0.92	0.90	1.82	8.22	10.04	272.00	63.0
Average	0.54	0.33	0.87	4.54	5.43	85.99	76.3
			Fertilizer 15-0-0				
May 4	0.46	0.41	0.87	3.20	4.07	1.27	82.0
May 11	0.35	0.23	0.58	4.00	4.58	2.20	82.0
May 18	0.36	0.32	0.68	—	—	4.33	80.0
June 1	0.63	0.22	0.85	5.72	6.57	6.46	75.4
June 8	0.30	0.24	0.54	3.20	3.74	11.30	78.6
June 15	0.35	0.52	0.87	3.88	4.75	25.40	77.8
June 29	0.49	0.40	0.89	3.93	4.82	54.90	74.7
July 13	0.20	0.30	0.50	3.87	4.37	140.00	75.8
July 27	0.59	0.39	0.98	4.58	5.56	413.00	73.0
Aug. 10	1.01	0.83	1.84	8.15	9.99	193.00	63.3
Average	0.47	0.39	0.86	4.50	5.38	85.19	76.3
			No fertilizer				
May 4	0.75	0.07	0.82	3.50	4.32	1.26	81.4
May 11	0.25	0.23	0.48	4.07	4.55	2.32	82.3
May 18	0.30	0.36	0.66	—	—	4.75	81.6
June 1	0.63	0.18	0.81	5.47	6.28	7.42	76.2
June 8	0.25	0.34	0.59	3.42	4.01	12.70	77.9
June 15	0.68	0.13	0.81	4.14	4.95	20.50	76.2
June 29	—	—	—	—	—	72.00	74.2
July 13	0.23	0.38	0.61	4.62	5.23	140.00	74.7
July 27	1.00	0.12	1.12	6.94	8.06	277.00	72.0
Aug. 10	0.98	0.80	1.78	8.22	10.00	227.00	64.1
Average	0.56	0.29	0.85	5.05	5.93	76.50	76.1

carbohydrates. This decrease is followed shortly by a general, and sometimes a sudden, increase in carbohydrates in the plants as the cotton bolls become larger and more succulent. Boll maturity is generally characterized by a very sharp rise in concentration of carbohydrates, particularly polysaccharides.

The general level of carbohydrates in plants from the Wilson soil for all treatments was higher than that in plants grown on the Houston soil. The data show that the disaccharides, regardless of treatment, were responsible for the greater part of this difference. The

average concentration of disaccharides in unfertilized plants from the Wilson soil was slightly greater than 2½ times that found in corresponding plants from the Houston soil. The difference in water content of plants from the two soils was of sufficient magnitude to exert some influence on the carbohydrate metabolism. On an average, the plants from most of the plats, both fertilized and unfertilized, on the Wilson soil contained about 4% less water than did those from plats on the Houston soil.

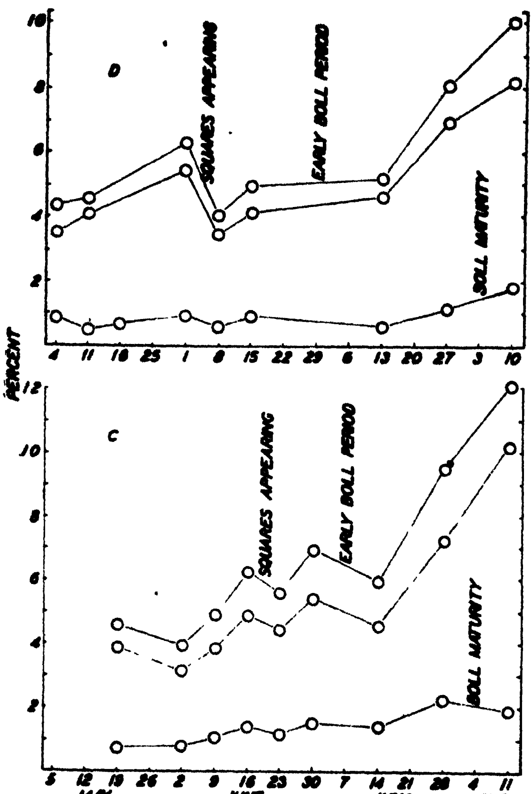

FIG. 1.—Seasonal changes in carbohydrates of cotton plants grown on Wilson fine sandy loam (C) and Houston black clay (D). Reading upward the graphs represent total sugar, polysaccharide, and total carbohydrate content, respectively.

The monosaccharide and disaccharide contents of cotton plants grown on the Wilson soil were affected by fertilizer treatment. The fertilizer effect was more apparent on the monosaccharides than on the disaccharides. All of the fertilizer treatments, except 15–0–0, had some influence. The fact that all other treatments contained phosphorus may be significant. Three treatments used on the Wilson soil are presented in Fig. 2C, which shows the effect of fertilizers on the monosaccharides at successive stages of growth. The graph shows (a) normal changes in cotton as represented by the unfertilized check, (b) the effect of 0–15–0 fertilizer, and (c) the lack of effect of 15–0–0 fertilizer. The increased concentrations from the 0–15–0 treatment occurred during the fruiting period of the cotton plant, corresponding to the dates June 12 to July 28, inclusive. The sample of June 30 is missing for the 0–15–0 series, but the data for the 3–9–3 plat (Table 1) substantiate the trend of the 0–15–0 data as given. No consistent fertilizer effect was indicated for these fractions in plants grown on the Houston soil. The 0–15–0 fertilizer, however, produced a generally higher concentration of monosaccharides than the 15–0–0, while the converse is true for the disaccharides.

The storage carbohydrates, represented by the polysaccharides appeared to be slightly influenced by fertilizers, but the effect was limited to the 15–0–0 and 0–15–0 ratios. Similar trends were noted in the results from plants grown on both soil types. The data from plants grown on the Houston soil indicate the fertilizer effect better. In Fig. 2D are graphs which compare the effects of treatments 15–0–0 and 0–15–0 on the polysaccharide content of plants grown on Houston soil. As compared with the "no treatment" plat, nitrogen (15–0–0) tended to show a concentration of storage carbohydrates equal to that of unfertilized plants during the early part of the season, while during the latter part a lower concentration was indicated. Phosphorus (0–15–0), on the other hand, caused less storage early in the season, but induced an equal or a greater reserve than that of unfertilized plants late in the season.

These concentration effects from ratios 15–0–0 and 0–15–0 appeared to be correlated with plant growth, using plant weight as an index of growth. On the Houston soil, from May 4 to June 8, plant growth in the 0–15–0 plats was superior to that on the untreated and 15–0–0 plats. During this same period, the storage of carbohydrates in plants from the 0–15–0 plats was lower than that in plants from the untreated and 15–0–0 plats. Later in the season, June 29 to August 10, the average plant weight on the 15–0–0 plats was greater than that on the untreated and 0–15–0 plats, and during that time storage of carbohydrates in plants from the 15–0–0 plats was consistently lower than that of unfertilized plants and those receiving phosphorus (0–15–0). A similar correlation is found in the data from the Wilson soil. The corresponding periods for comparison were May 19 to June 16 and June 23 to August 11.

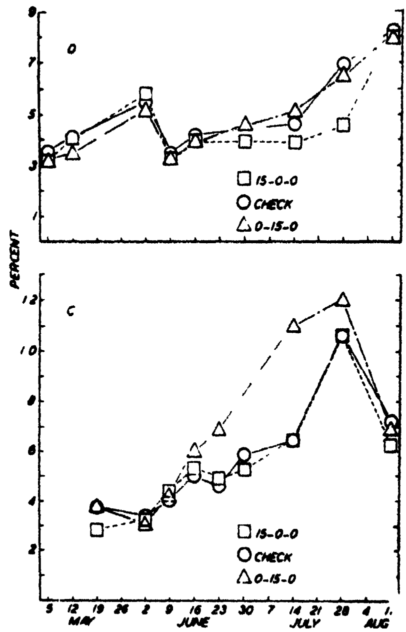

FIG. 2.—Seasonal changes in monosaccharide content of cotton plants grown on Wilson fine sandy loam (C) and polysaccharide content of plants produced on Houston black clay (D) under different fertilizer treatments.

DISCUSSION

The data given here on the effects of fertilizers on monosaccharides in cotton plants grown on a Wilson soil substantiate those reported previously (3) for Wilson clay loam. The failure of this carbohydrate fraction to respond to the fertilization of plants on the Houston soil may be connected in some way with the observed difference in the

response of the two soils to fertilizers. It has been noted (5) that soils of the Wilson series give the best response to fertilizer ratios in which the amount of phosphate exceeds that of nitrogen, while the converse seems to be better adapted for Houston black clay. These differences have been obtained where the rate of application was 600 to 900 pounds per acre. The results from associated studies on the electro-dialyzable components of cotton plants (6) from the same plats from which plants were selected for the carbohydrate work throw some light on the problem. These data show that the total phosphorus was higher in plants from untreated plats on the Houston soil than in those from corresponding plats on the Wilson soil. The addition of equal amounts of phosphorus to the two soils produced a higher concentration of total phosphorus in plants from the Wilson soil in every case.

The decrease in polysaccharide content with a corresponding increase in plant weight, as noted for treatments 15–0–0 and 0–15–0, might be looked upon as a plant effect and not a direct fertilizer effect. The fertilizer is indirectly concerned, of course, in that it is responsible for the increase in plant weight. There is evidence, however, which favors a direct effect on concentration of polysaccharides in the plant from the addition of nitrogen and phosphorus to the soil. It has been observed by many workers that phosphate fertilizers induce earlier maturity in cotton, while a nitrogenous fertilizer tends to prolong the vegetative condition. It is reasonable to assume that a plant which develops faster than another during a certain period will store a smaller amount of carbohydrates than the less vigorous plant.

The use of the whole cotton plant for studying the effects of fertilizers on its carbohydrate composition at successive stages of growth is somewhat less effective than the use of tops and roots separately. While the plant is small and in the formative stage, the whole plant seems to be satisfactory. When the plant has developed and formed squares and bolls and the cotton approaches maturity, it is advantageous to consider the composition of the plant parts to ascertain the effect of soil treatments on plant composition.

SUMMARY

Similar seasonal changes in carbohydrate concentrations were noted for cotton plants grown on Wilson fine sandy loam and Houston black clay soils in Texas. The level of carbohydrates was greater in plants from the Wilson soil than those from the Houston. Drought conditions on the Wilson soil probably affected this level.

The monosaccharide, disaccharide, and polysaccharide contents of plants from the Wilson soil were affected by fertilizers, while only the polysaccharides in plants from the Houston soil seemed to be definitely influenced. A correlation of fertilizer treatment and plant growth was also noted for plants from both soils.

Under the conditions of the experiment it was found that whole plants do not reflect the effect of fertilizer treatment as well as root and aerial segregates studied previously.

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THE "ALKALI TEST" AS A QUALITY INDICATOR OF MILLED RICE[1]

Jenkin W. Jones[2]

RICE varieties differ materially in milling and cooking quality. Millers naturally prefer varieties that give high yields of head rice (whole kernels) because unbroken kernels are the most valuable product obtained in rice milling. Consumers, on the other hand, are interested primarily in cooking quality. The kernels of different rice varieties may retain their shape after boiling and be either tender and flaky or firm and somewhat sticky, or they may break down into an unattractive pasty mass.

The observed differences in cooking quality are due apparently to variations in the size and shape of the kernels and to inherent differences in the character of starch in the kernels.

In breeding for improved quality a simple test is needed so that varieties and selections of undesirable cooking quality can be eliminated before carrying them through extensive tests. In general, differences in the chemical composition of varieties have not been found to be closely associated with their accepted culinary quality.

Warth and Darabsett,[3] however, reported that rice kernels of different varieties disintegrated in alkali solutions in a consistent order. Kernel disintegration and gelatinization was completed in some varieties in 24 hours, but in others it was incomplete after that time as indicated by a diffused white area adjacent to the kernels.

These studies suggested the possibility of using the alkali test as an indicator of culinary quality in rice varieties.

The experimental objectives reported here were to determine (1) the effect of a dilute solution of KOH on milled kernels of the rice varieties grown in the United States, (2) whether the effect of the solution on the kernels of a variety was consistent from year to year, and (3) whether the nature of kernel disintegration in the solution was associated with the cooking quality.

RESULTS

Milled kernels of seven varieties were tested in a 3% solution of potassium hydroxide in 1933. The kernels of Rexoro, Fortuna, Caloro, and Blue Rose disintegrated into clear masses in 24 hours and those of Early Prolific, Lady Wright, and Edith into opaque masses with white diffused areas near the kernels. The kernels of none of these varieties disintegrated in 24 hours in 1% or 2% solutions, but all disintegrated in a 2.38% solution. This strength was used in all subsequent tests because it indicated differences in varieties that were not so apparent in either weaker or stronger solutions. A stock solution of alkali was

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication August 26, 1938.

[2]Senior agronomist.

[3]Warth, F. J., and Darabsett, D. B. Disintegration of rice grains by means of alkali. Agr. Res. Inst., Pusa, Bul. 38. 1914.

made up each year by adding 100 grams of pure KOH to 2,000 cc of water. The solution was diluted to the desired strength when used. All tests were made at room temperatures of about 75° to 85° F, unless otherwise stated.

Mature panicles of varieties were collected at the four rice experiment stations in Louisiana, Texas, Arkansas, and California each fall from 1933 to 1936. After drying, seed from one panicle of each variety was milled for a uniform time in a "Minghetti rice mill," a small laboratory mill of the pearling cone type. Five milled kernels of each variety were then placed in a 2.38% solution of potassium hydroxide in Petri dishes. Four varieties usually were tested in one Petri dish. The appearance of the kernels was noted after 24 hours.

The appearance of the kernels of various varieties at the end of 24 hours is shown in Table 1. On the basis of disintegration, the samples were placed in three classes, *viz.*, clear, opaque, and intermediate. The varieties listed in Table 1 are placed in four groups on the basis of their reaction in the alkali solution. In all years tested, kernels of Blue Rose, Supreme Blue Rose, Zenith, Acadia, Caloro, and Colusa (group 1) disintegrated into clear masses and those of Early Prolific, Early Blue Rose (Wright's), Edith, and Lady Wright (group 2) from the southern states into opaque masses. The kernels of Early Prolific and Lady Wright from California also disintegrated into opaque masses in three of the four years tested.

Kernels of Fortuna, Rexoro, Iola, and Delitus, group 3, were clear in some years and intermediate in others. Kernels of Shoemed and Nira also were clear or intermediate, except for the 1936 samples from Texas. Intermediate samples of these varieties usually became clear in slightly stronger solutions. This, however, did not occur in varieties that were consistently opaque.

The kernels of Honduras, Vintula, Carolina Gold, Stormproof, and Mortgage Lifter, group 4, were not consistent in behavior from year to year. In most tests they were intermediate, but in others they were clear or opaque.

Variations in seasonal environmental conditions probably had more effect on the character of the starch in some varieties than in others. In this connection, it is of interest to note that the kernels of Honduras, Vintula, and Carolina Gold from California were clear, whereas kernels of the same varieties from Arkansas, Louisiana, and Texas were intermediate or opaque. Climatic conditions in California are very different from those in Arkansas, Louisiana, and Texas, and the effect of these differences on maturing of the rice kernels may account in part for the differences observed.

There is also the possibility that in some tests a panicle not representative of the variety was used, although precautions were taken to avoid such errors.

The effect of a 2.24% solution of alkali on the kernels of 16 varieties of rice is illustrated in Figs. 1 to 4.

The kernels of the Blue Rose, Supreme Blue Rose, Calady, Caloro, and Colusa varieties, group 1, all disintegrated into clear masses. Kernels of Early Prolific and Lady Wright, group 2, were opaque each in 15 of 16 tests. The two exceptions were kernels from the 1933

TABLE 1.—*Disintegration of kernels of rice varieties in a 2.38% solution of KOH.*

Variety	C. I. No.	Degree of disintegration after 24 hours*																Number of tests in which kernels disintegrated into masses that were			Total number of tests
		Louisiana crop of					Texas crop of				Arkansas crop of			California crop of							
		1932	1933	1934	1935	1936	1933	1934	1935	1936	1933	1935	1936	1933	1934	1935	1936	Clear	Intermediate	Opaque	
Group 1 (All Clear)																					
Blue Rose	1962	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	Cl.	Cl.	Cl	Cl.	Cl.	15	0	0	15
Supreme Blue Rose	5793	—	Cl.	—	Cl.	—	—	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	—	—	—	—	8	0	0	8
Calady	7786	—	Cl.	—	Cl.	Cl.	—	Cl.	Cl.	Cl.	—	Cl.	Cl.	—	Cl.	Cl.	Cl.	11	0	0	11
Zenith	7787	—	—	—	Cl.	Cl.	—	—	Cl.	Cl.	—	Cl.	Cl.	—	—	—	Cl	7	0	0	7
241B(pl)31-2		—	—	—	—	Cl.	—	—	Cl.	Cl.	—	Cl.	Cl.	—	Cl	Cl	Cl.	8	0	0	8
Caloro	1561-1	Cl.	Cl.	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	14	0	0	14
Colusa	1600	—	Cl.	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	—	Cl.	Cl	—	Cl.	Cl.	Cl.	12	0	0	12
Acadia	1988	—	Cl.	—	—	—	—	Cl.	—	—	—	—	—	Cl.	Cl.	—	—	4	0	0	4
Group 2 (Mostly Opaque)																					
Early Prolific	5883	Op.	Op	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Int.	Op	Op.	Op.	0	1	15	16
Early Blue Rose (Wright's)	7790	—	—	—	Op.	Op.	—	—	Op.	Op.	—	—	Op.	—	—	—	—	0	0	5	5
Lady Wright	5451	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Int.	Op.	Op.	Op.	0	1	15	16
Latex	7788	—	Op.	—	Op.	Op.	—	Op.	Op.	Op.	—	Op.	Op.	Op.	—	Op.	Op.	0	0	11	11
Early Wright	—	—	Int.	Op.	—	—	—	Op.	—	—	—	Op.	Op.	—	—	—	—	0	1	4	5
Edith	2127	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Int.	Op	Cl	Int.	1	2	13	16
Group 3 (Mostly Clear and/or Intermediate)																					
Delitus	1206	—	Int.	Cl.	Int.	Int.	—	Cl.	Int.	Int.	—	Cl.	—	—	Cl.	Cl.	Cl.	6	5	0	11
Fortuna	1344	Cl.	Int.	Cl.	Int.	Int.	—	Cl.	Int.	Int.	—	Cl.	Int.	—	—	—	Cl.	5	6	0	11
Rexoro	1779	Cl.	Int.	—	Int.	Int	—	Cl.	Int	—	—	—	—	—	—	—	—	2	4	0	6
Nira	2702	—	—	Cl.	Int.	Int.	—	Cl.	Int.	Op.	—	Cl.	Cl.	—	—	—	Cl.	5	3	1	9
Iola	4559	—	Int.	—	Int.	Int.	—	—	—	Cl.	—	—	—	—	—	—	—	1	3	0	4
Shoemed	3625	—	Int.	Cl.	Int.	Int.	—	Cl.	Int.	Op.	—	Cl.	Int.	—	—	—	Cl.	4	5	1	10
Group 4 (Usually Intermediate)																					
Honduras	1643	—	Int.	Int.	Int.	Int.	—	Op.	Int.	Int.	—	Int.	Op.	—	Cl.	Cl.	Cl.	3	7	2	12
Vintula	1241	—	Int.	Int.	Int.	Int.	—	Int.	Op.	Int.	—	Cl.	Op.	Cl.	—	Cl.	—	3	6	2	11
Carolina Gold	1645	—	Int.	—	Int.	Op.	—	Int.	Int.	Int.	—	Cl.	Int.	—	Cl.	—	Cl.	3	6	1	10
Stormproof	7705	—	Int.	Int.	Int.	Op.	—	Op.	Int.	Int.	—	Op.	Int.	—	—	—	—	0	6	3	9
Mortgage Lifter	5550	—	—	—	Int.	Int.	—	Op.	Op.	Int.	—	Int.	Op.	—	—	—	—	0	4	3	7

*Cl. = Clear; Op. = Opaque; and Int. = Intermediate.

California crop that were intermediate. These results indicate that the character of the starch in these two groups of varieties probably is inherently different, accounting for the fact that in each group the nature of the disintegration of the kernels in alkali solutions was consistent, except as noted.

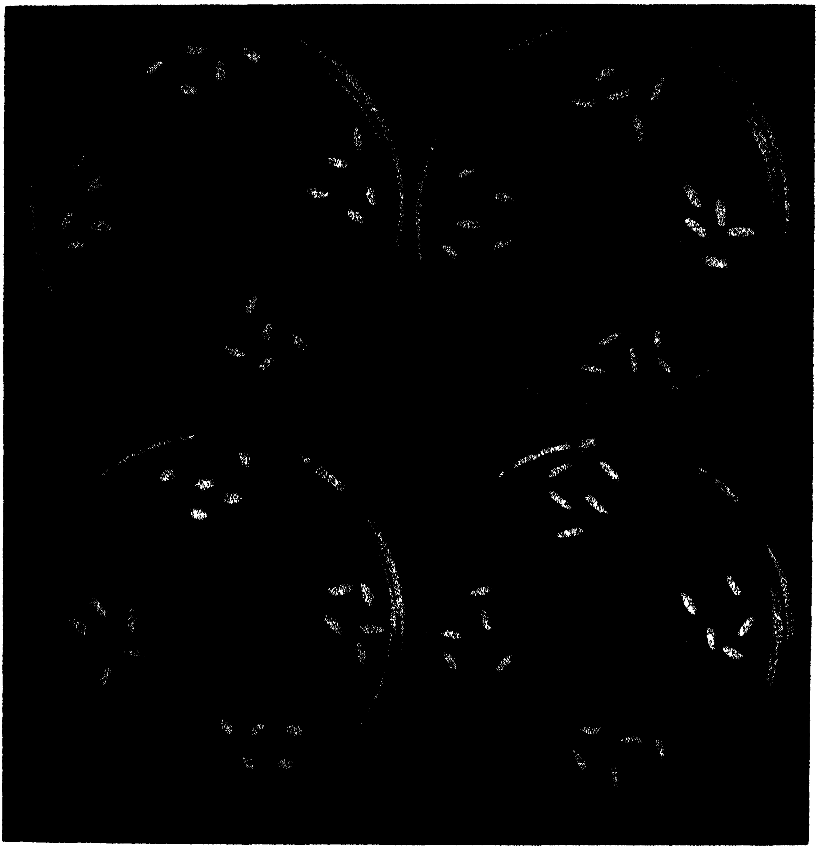

FIG. 1.—Kernels just after placement in the solution at 10:45 a.m., June 17, 1938. 1, Blue Rose; 2, Early Prolific; 3, Calady; 4, Early Blue Rose; 5, Caloro; 6, Lady Wright; 7, Colusa; 8, Edith; 9, Fortuna; 10, Honduras; 11, Rexoro; 12, Vintula; 13, Nira; 14, Carolina Gold; 15, Delitus; and 16, Stormproof.

The kernels of Fortuna, Rexoro, Nira, and Delitus, group 3, were about equally divided between clear and intermediate types of disintegration. This indicates that in these varieties the character of the starch deposited in the kernels is probably more easily affected by environmental conditions than that of the varieties listed in either groups 1 or 2. The kernels of Honduras, Carolina Gold, Stormproof, and Vintula, group 4, were also inconsistent in type of disintegration. It is also possible that the starch of the varieties listed in groups 3

and 4 may consist of a mixture similar in some respects to that present in varieties of groups 1 and 2. Warth and Darabsett[4] have shown that a portion of the starch in some rice varieties is liquefied at relatively low temperatures, while the remainder requires a higher temperature for liquefication.

FIG. 2.—Kernels of 1, Blue Rose; 3, Calady; 5, Caloro; and 7, Colusa began to disintegrate 1¾ hours after being placed in the solution (12:30 p.m., June 17, 1938).

The kernels of Blue Rose and Caloro, group 1, which were consistently clear, are usually rather firm and slightly sticky when cooked by boiling. Kernels of Fortuna and Rexoro, group 3, are usually tender and flaky after cooking. Early Prolific and Lady Wright, group 2, from the South, which were consistently opaque, do not hold their shape so well in cooking and are likely to be pasty and of inferior quality.

Fortuna and Rexoro of group 3 are believed to be superior in culinary quality to Blue Rose and Caloro of group 1, and Blue Rose is

[4]WARTH, F. J., and DARABSETT, D. B. The fractional liquefication of rice starch. India Dept. Agr. Mem. Chem. Ser., 3(5):135–146. 1914.

likewise believed to be superior to Early Prolific of group 2. In general, therefore, there appears to be some association in certain varieties between the type of kernel disintegration in an alkali solution and the cooking quality. The kernels of varieties believed to be of the best (tender and flaky) culinary quality usually were clear or intermediate

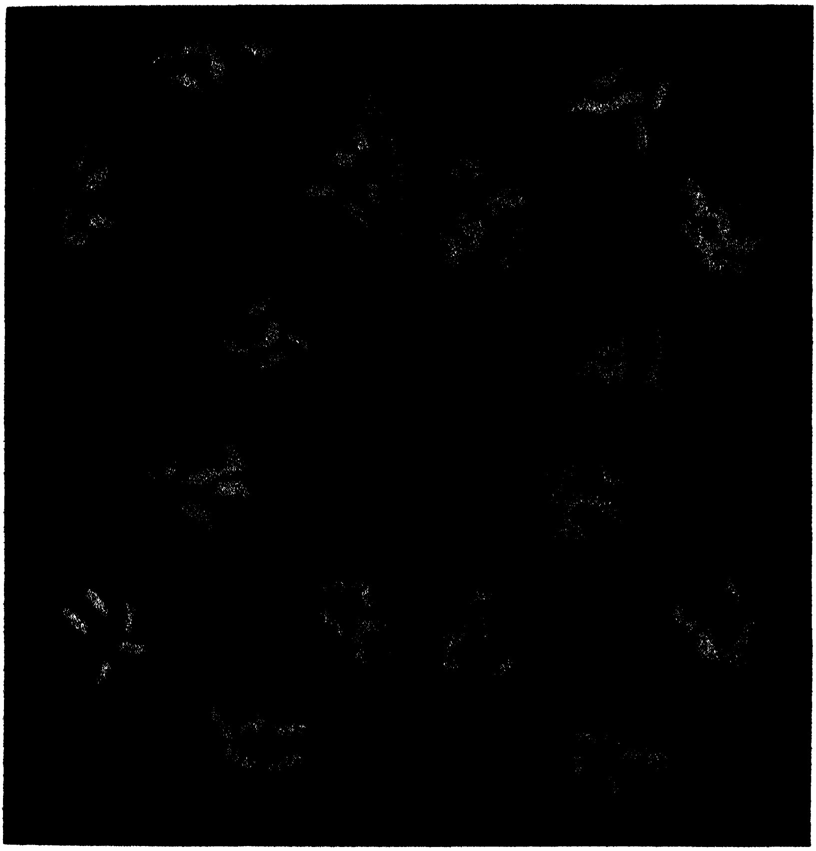

FIG. 3.—Kernels of all varieties began to disintegrate 5¼ hours after placement in the solution (4:30 p.m., June 17, 1938). There was more disintegration in 1, Blue Rose; 3, Calady; 5, Caloro; and 7, Colusa kernels than in those of the other varieties. The varieties most resistant to disintegration were 2, Early Prolific; 4, Early Blue Rose; 6, Lady Wright; and 8, Edith.

(group 3), and those believed to be of poorer quality were opaque, group 2. The varieties listed in group 4, which were the least consistent in behavior, are also believed to be of better cooking quality than most of those listed under groups 1 and 2.

Early Prolific and Blue Rose are medium-grain varieties and the cooking quality of Early Prolific, of opaque reaction, is generally believed to be less desirable than that of Blue Rose, of clear reaction. Likewise, the cooking quality of the long-grain variety, Lady Wright,

of opaque reaction, is believed to be less desirable than that of the long-grain varieties Fortuna, Rexoro, and Nira, which were of clear or intermediate reaction. Edith and Lady Wright, long-grain varieties, were both opaque in reaction but Edith is believed to be of better

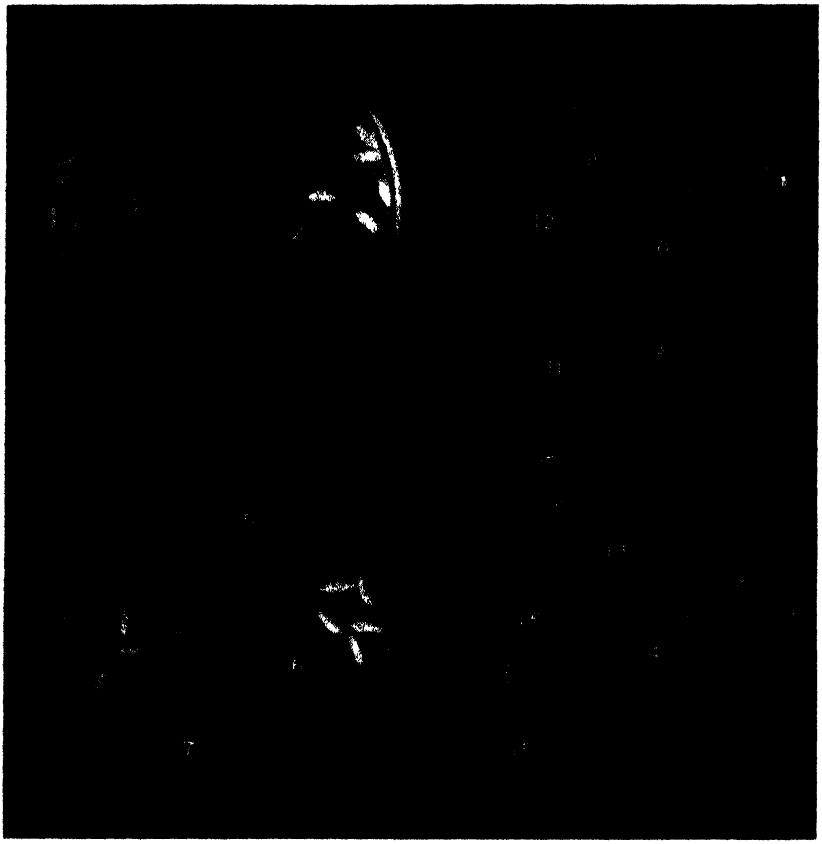

FIG. 4.—Twenty-four hours after placement in the solution (10:45 a.m., June 18, 1938) the kernels of 1, Blue Rose; 3, Calady; 5, Caloro; and 7, Colusa disintegrated into clear masses; those of 2, Early Prolific; 4, Early Blue Rose; 6, Lady Wright; and 8, Edith were more resistant and opaque; and those of 9, Fortuna; 10, Honduras; 11, Rexoro; 12, Vintula; 13, Nira; 14, Carolina Gold; 15, Delitus; and 16, Stormproof disintegrated more completely and were somewhat less opaque than 2, Early Prolific; 4, Early Blue Rose; 6, Lady Wright; and 8, Edith.

cooking quality than Lady Wright. Varieties showing the same reaction may differ in cooking quality but probably to a lesser extent than varieties of different reaction.

The results, while not so consistent as might be desired, do indicate that a simple test of this nature may be used to advantage in preliminary testing for quality.

Rice varieties that differ materially in kernel size or shape, in the time required for cooking, or in their reaction to alkali solutions should not be blended or mixed when placed on the market.

EFFECT OF TEMPERATURE

Tests in an alkali solution were made in 1935 at constant temperatures of 20°, 25°, 30°, and 35° C. The kernels of Blue Rose, Caloro, Rexoro, and Iola appeared to be more completely disintegrated at 30° and 35° than at 20° and 25° C, whereas those of Early Prolific and Lady Wright were more completely disintegrated at 20° and 25° than at 30° and 35° C. Kernels of Early Prolific and Lady Wright, as has been stated, are more resistant to disintegration in alkali solution than are those of Blue Rose, Zenith, Caloro, and other varieties that usually disintegrated into clear or intermediate masses.

TESTS OF SAMPLES FROM COMMERCIAL MILLS

In the fall of 1937, 29 samples of milled Early Prolific and 46 samples of milled Blue Rose rice were obtained from commercial mills in Arkansas, Louisiana, and Texas. All kernels from 26 of the Early Prolific samples tested in an alkali solution were opaque. In the other three samples from 2 to 8% of the kernels were clear, similar in appearance to those of disintegrated Blue Rose.

The kernels in 19 of the Blue Rose samples were all clear, but in the remaining 27 samples from 4 to 36% of the kernels tested were opaque, similar in appearance to those of Early Prolific.

Of the 46 Blue Rose samples tested, 58.7% thus contained mixtures of opaque kernels similar in appearance to disintegrated Early Prolific, whereas only 10.3% of the 29 Early Prolific samples contained mixtures of clear kernels that reacted like those of Blue Rose. These results indicate that milled rice consisting of a mixture or blend of kernels of the same shape and appearance but that are clear and opaque in reaction can be detected with reasonable certainty.

SUMMARY

A simple test for quality is needed in breeding rice to permit the discarding of varieties and selections of inferior quality after preliminary nursery tests. Data on an "alkali test" as an indicator of culinary quality are presented here.

Milled kernels of rice varieties were immersed in a dilute solution of potassium hydroxide and the nature of kernel disintegration was observed.

The type of disintegration was consistent in all samples of certain rice varieties but was inconsistent in others.

There is evidence of some association in cooking quality and the type of kernel disintegration. Varieties of similar grain types in which the kernels disintegrate into clear and/or intermediate masses in general are believed to be of better cooking quality than those that disintegrate consistently into opaque masses.

The alkali test permits the detection of certain common though undesirable varietal mixtures of milled rice.

NOTE

A NEW CLOVER FOR THE BLACK LANDS IN THE SOUTH

A CLOVER that is locally called "Wild European clover," or Lappacea clover (*Trifolium lappaceum*), has shown that it may become very valuable on the heavy clay soils of the "Black Belt" of Alabama and other southern states. This clover, so far as is known, was first found in this country in 1923. It was first found along the railroad at Snow Hill, Alabama, and was reported by Doctor A. J. Pieters in SCIENCE, Vol. 59, No. 1515, pages 39 to 40, in 1924. It was sent in to the U. S. Dept. of Agriculture for identification from Mississippi in 1926. In 1929 one plant was found in a field of oats near Marion Junction, Alabama. At present this farmer has 230 acres of land with this clover on it.

In 1935 it was found on a farm near Montgomery, Alabama. At present this farmer has about 40 acres in the clover. In 1938 many other scattered patches of the clover have been reported over various parts of the Black Belt.

The plant is a creeping annual with a dense pubescence on the leaves and stems. On good soil it reaches a height of 18 inches. It produces a large yield of hay and is an excellent pasture plant. It produces an abundance of seed which are a little larger than those of white clover. It reseeds when pastured or when cut for hay. The seed germinate in the fall and the plant reaches a height of 4 or 5 inches in February. It makes rapid growth in the spring and dies in June. It is not known how far north it is cold-hardy, but it has never been killed by cold in middle Alabama. A few seed are available for distribution by the Agronomy Department of the Alabama Experiment Station to experiment station workers who may be interested in testing it in an introductory way.—D. G. STURKIE, *Alabama Agricultural Experiment Station, Auburn, Ala.*

BOOK REVIEWS

FARM GAS ENGINES AND TRACTORS

By Fred R. Jones. New York: McGraw-Hill Book Company, Inc. Ed. 2. XII+486 pages, illus. 1938. $3.75.

THIS is the second edition of the book by the same name, published in 1932. An important change is the rearrangement of material so that the two parts of the preceding edition are combined, thus eliminating the duplication that necessarily followed the division into a part which treated of the fundamentals of simple internal-combustion engines and the small stationary farm-type engine, and a part which then considered the detailed construction and operation of farm tractors.

New chapters are added on Diesel engine construction and operation, fuels and their character, and electric starting and lighting equipment. Illustrations are brought up-to-date in conformity with the rapid changes that have taken place in recent years.

It is primarily adapted as an up-to-date textbook for use in agricultural colleges, but should also prove useful to mechanics, service men, and owners and operators. (H. B. T.)

THE PRINCIPLES OF SOIL SCIENCE

By Alexius A. J. de Sigmond. Translated from the Hungarian by Arthur B. Yolland. Foreword by Sir John Russell. London: Thomas Murby & Co. XIV+362 pages, illus. 1938. 22/6 net.

THIS book is a translation and adaptation for English students of one of somewhat longer form published in Hungarian some years ago by Prof. de Sigmond. It aims primarily at presenting, fairly exhaustively, the present status of the science of pedology and deals with genetics, agronomy, systematics, and cartography. The author, who himself felt the importance of an English translation, undertook the work and made the adaptation to the English student. This latter consisted in omitting details of more local interest and also the sections in the original which dealt with soil physics and soil microbiology in which, as Prof. de Sigmond states, "English soil literature is already so rich".

It seems superfluous to say much concerning the volume's contents since the author himself states that it is an almost full outline of the subjects covered and deals with both the author's work and that of other soil scientists.

As Sir John Russell intimates in his foreword, any book on soil science by such an internationally recognized authority as Prof. de Sigmond is sure to be of great value to other soil scientists of the world.

Besides some 38 illustrations the volume also has a good subject and author index. (R. C. C.)

THE SOILS OF PALESTINE: STUDIES IN SOIL FORMATION AND LAND UTILIZATION IN THE MEDITERRANEAN

By A. Reifenberg. Translated by C. L. Whittles. London: Thomas Murby & Co. VIII+131 pages, illus. 1938. 14s. net.

THE author of this little book is a lecturer on agricultural chemistry and soils in the Hebrew University in Jerusalem, while the translator is soil chemist at the West of Scotland Agricultural College.

The purpose of the volume seems to be to bring before the minds of those interested the present status of the soils of Palestine from the standpoint of fertility and erosion losses.

The author is especially interested in the problems presented by Mediterranean type soils which he says have been steadily deteriorating for fifteen hundred years. The subject is especially pertinent at present in light of the new Jewish immigration. In fact the last chapter of the book is given over to the history and present status of the Zionist colonisation movement.

For the most part the book is a technical treatment of the problems involved and includes considerable data and discussions of the processes of formation of Palestine soils, the effect of Mediterranean

climate on soil formation, crop adaptation, irrigation, and manuring problems. There are 10 illustrations and a number of figures in the text, also a bibliography at chapter ends. The contents should be valuable to those interested in the climatic aspects of soil formation. (R. C. C.)

SOILS OF THE LUSITANO-IBERIAN PENINSULA

By Emile H. del Villar. Translated by G. W. Robinson. London: Thomas Murby & Co. 416 pages. 1937. Paper cover; also, map in separate folder. 40/ net.

THE author of this work is a Spanish geobotanist and edaphologist, also president of the Mediterranean Subcommission of the International Society of Soil Science. Prof. Robinson in his translation has somewhat abridged the original. The volume is rather large owing to the fact that the translator presents each chapter first in Spanish then in English. The volume takes up classification and nomenclature, acid-humic soils, siallitic soils, calcareous soils, saline soils, alluvial soils and modification of these. At the end of each chapter are given many analyses of the soils described.

The text contains a few plates, is printed on good paper with clear type, but has no index or table of contents. The accompanying map is a large folding one with a description given at the end of the main volume. It can be furnished by the publishers, rolled and suitable for hanging.

As the translator states, the study of pedology is world wide and a worker who is acquainted only with the soils of his own country has only a partial view of the subject as a whole. (R. C. C.)

CHROMOSOME NUMBER RELATIONSHIPS IN THE LEGUMINOSAE

By Harold A. Senn. Bibliographia Genetica XII: 175-336. 1938.

THIS is a cytological monograph of the family comprising the chromosome numbers in 436 species of 74 genera. The frequency of polyploidy in the Leguminosae is very low, only 23% being polyploids or dervied from polyploids. Intraspecific polyploidy is rare and intrageneric polyploidy of only occasional occurrence. Intergeneric and intergroup aneuploidy is a common relationship, but intrageneric and intraspecific aneuploidy is less common. Northern and wide distribution is not always associated with polyploidy. Higher chromosome numbers are associated with perennial condition. The woody legumes were found to have on the average higher chromosome numbers than the herbaceous ones. A number of instances among closely related races or species are cited where the perennial has the higher number. These findings indicate that in the Leguminosae at least some of the woody perennial species may have arisen from herbaceous annual ancestors.

A phylogenetic tree is given from which the following lineages may be mentioned: From the base line of primitive Papilonatae springs a branch carrying the Sophoreae with 9 and 14 chromosomes and the closely related Podalyrieae (9) and the related Caesalpinioideae.

From the same root but on a different branch are the Galegeae (8, 7, 6, 10, 11) with the Loteae (8, 7, 6) and the Hedysareae (8, 7, 9, 10, 11, 20) more distally attached.

Three other main stems spring from the base line all assumed to have the basic number 8. These main stems are interrelated in the following way: The Grotalarinae (8) and Spartiinae with the Cytisinae (12, 24) stem from the Genisteae which through Ononis (15, 16) connect with the second main stem carrying the Trifolieae (8, 7). The closely related Cicer (7, 8) and Vicieae (7, 6, 5) connect the first and second main stem with the third carrying Abrus (11)and the closely related Phaseoleae (11, 12, 8, 20, 21).

The literature list covers 12 pages. There are 102 figures among which 15 maps, 2 frequency distribution graphs on annual and perennial, herbaceous and woody members related to chromosome number, 2 polygons on diploidy and polyploidy, and all original counts are authenticated by original drawings. (B. R. N.)

AGRONOMIC AFFAIRS

SUMMARY AND INDEX OF WPA RESEARCH PROJECTS

THE results of some 2,000 research projects carried on as part of the Federal work relief program are summarized briefly in a digest and index which has been published by the Works Progress Administration. This volume of 291 pages contains a concise statement of the principal conclusions of each study and an alphabetical subject index to the contents. The reports on these projects touch upon nearly every field of natural and social science and many of them have appeared in the form of articles in scholarly journals. However, several hundred of the reports summarized in this index are in manuscript form, and arrangements have been made with the American Documentation Institute whereby micro-film copies of the original reports will be furnished at nominal rates for the use of research specialists.

A small edition of this volume has been prepared for distribution to the larger public and university libraries, where it will be available for reference, and for government departments, industrial concerns, and research foundations. A limited supply of copies of this Index of Research Projects are still available. Requests should be addressed to the Works Progress Administration in Washington.

BIBLIOGRAPHY ON MINOR ELEMENTS AND PLANT NUTRITION

A THIRD edition of "Bibliography of References to the Literature on the Minor Elements and Their Relation to the Science of Plant Nutrition" is contemplated by the Chilean Nitrate Educational Bureau early in 1939. It is expected that the volume will include approximately 4,700 abstracts and references.

In order to meet requests for this edition, the Bureau is desirous of knowing as far in advance of publication as possible what the demand will be. Copies may be obtained at the nominal charge of $1.00 to cover printing and postage. Orders should be placed with the Chilean Nitrate Educational Bureau, Inc., 120 Broadway, New York City.

FILM-STRIP PRICES

PRICES for film strips issued by the U. S. Dept. of Agriculture for the fiscal year 1938–39 are lower than those that were in effect during the past fiscal year, according to an announcement recently made by the Extension Service of the Department. Photo Lab, Inc., 3825 Georgia Avenue, N. W., Washington, D. C., was awarded the contract for film-strip production as the result of the low bid they submitted in competition with other firms.

The prices for film strips until June 30, 1939, will range from 45 to 65 cents each, depending upon the number of illustrations in the series. The majority of the 300 series that the Department has available will sell for 45 or 50 cents each. Film strips are available on such subjects as soil conservation, farm crops, dairying, farm animals, farm forestry, plant and animal diseases and pests, roads, farm economics, farm engineering, home economics, and adult and junior extension work. Lecture notes are provided with each film strip purchased, with the exception of those that are self-explanatory.

A list of available film strips and instructions on how to purchase them may be obtained by writing to the Extension Service, U. S. Dept. of Agriculture, Washington, D. C.

ABSTRACTS OF ROUND-TABLE CONFERENCE

MIMEOGRAPHED abstracts of the round-table conference on "Comparative Nutritive Value of Crops to Bring Out the Comparison and Advantages of Pasture and Hay Compared with Other Crops in Cost of Digestible Nutrients" have been prepared by Professor O. McConkey, Ontario Agricultural College, Guelph, Ontario, Chairman of the conference. The conference was held under the auspices of the joint Canadian and American Committee on Pasture Improvement at Ottawa in June, 1938, at the time of the summer meeting of the A. A. A. S.

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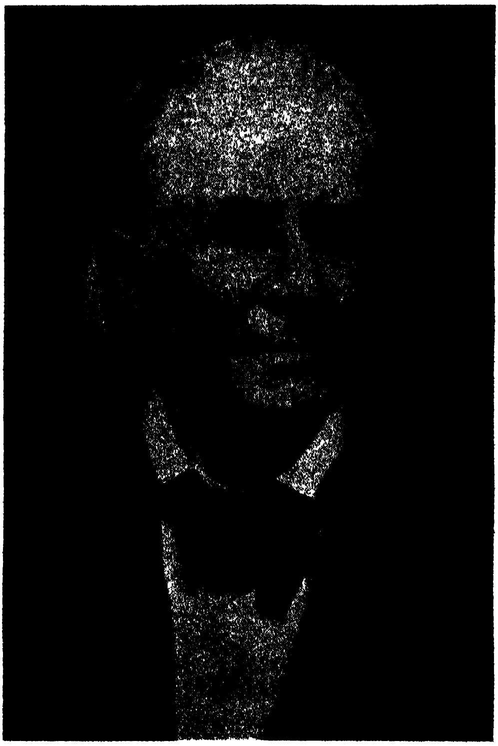
PUTTING SOIL SCIENCE TO WORK[1]

EMIL TRUOG[2]

JUST 120 years ago, soil science in America was put to work for the first time. The honor of doing this goes to Edmund Ruffin, whose father having died in 1810, was in 1813, at the age of 19, left in charge of a large plantation at Coggin's Point, located in the tide water area of Virginia. Not only because Edmund Ruffin was the first man in America to put soil science to work, but also because of the peculiar circumstances under which this was done, the speaker deems it appropriate to devote a large portion of this address to Ruffin's work.



EDMUND RUFFIN (1794–1865)

A successful farmer, father of soil chemistry in America, first to contend that upland mineral soils in the humid region are often acid, foremost authority of his time on the liming of land, brilliant writer, public benefactor, and a great patriot.

Edmund Ruffin, born in 1794, was in youth frail of health and restless of spirit. He read much of whatever came to hand and grew up in almost complete ignorance of the practical

[1]Presidential address delivered before the thirty-first annual meeting of the Society held in Washington, D. C., November 17, 1938.

[2]Professor of Soils, College of Agriculture, University of Wisconsin, Madison, Wis.

agricultural tasks which now faced him. After some elementary schooling, probably by his parents or private tutors, he left home for the first time at the age of 16 for Williamsburg to enter William and Mary College. His career there was short, having met Susan Travis, he soon returned home to take her in marriage, and then to enlist as a private in the War of 1812. After six months of military routine, he was mustered out, after which he immediately assumed control and direction of the Coggin's Point farm.

In attempting to give you a picture of the state of agriculture in Virginia at the time Ruffin started farming, and of the problems that Ruffin faced, I can do no better than to quote at length from Avery Craven's charming book entitled, *Edmund Ruffin, Southerner*[3] (pages 49 to 54). The quotation follows:

"'Of grain and pulse they provide commonly no more than they reckon that their families will require, for there are no towns as markets where they can sell them. . . . The one thing of which they make as much as they can is tobacco, there being always a vent for that at one time or another of the year.'

"Thus wrote an Old World observer of Virginia agricultural practices at the end of the seventeenth century. Unwittingly he had placed his finger on the central fact in the colonial history of the Old Dominion. Beginning in a wilderness, the early settlers had faced the possibility of a rapid degeneration to a grinding simplicity wherein every man and every group fashioned, from the materials the immediate environment afforded, the sum total of their consumption. Only the fortunate development of a profitable surplus of tobacco prevented a rapid lowering of standards and enabled them to procure, by exchange with the Old World, the comforts and luxuries of a mature and complex life and to reproduce in the forest a bit of 'merry England' itself, 'transported across the Atlantic. . . more merry, light and joyous than England had ever thought of being.'

"But it led, also, to the elevation of the first of those despotic Southern kings who brought so much of misery to their subjects. To base upon one staple alone, the whole of a standard of living centuries too old for its environment meant the establishment of a single-crop type of agriculture in which the sole object was immediate great yields regardless of future consequences. Such a system, under frontier scarcity of capital and labor, threw the burdens of abnormal production squarely upon the land, in a region where sod formation was poor, rainfall heavy and concentrated, and the harmful microorganisms unusually active. There could be but one result. Tobacco-growing meant soil exploitation, unit expansion, and ultimate abandonment of once fertile fields.

"Just what was implied is revealed in the comment of a second observer, three-quarters of a century later. 'The Virginians of the lower country are very easy and negligent husbandmen,' he wrote. 'New land is taken up, the best to be had, tobacco is grown on it for three or four years and then Indian corn as long as any will come. And in the end, if the soil is thoroughly impoverished, they begin again with a new piece and go through the rotation.' He pictured a world of widening fields and retreating forests; white servants, come to toil, giving way to negro slaves under pressure for economy; acres growing weary, falling from cultivation, and returning again to forest; in time, planters frayed a bit at the cuffs, out at the elbows, down at the heels, bitter and complaining, as farmers are wont to be, of returns that did not pay the cost of production. And then, while some held on,

[3]New York: D. Appleton and Company. 1932.

shifting crops and yielding standards, others, more easily discouraged or more quick to accept the inevitable, according to the point of view, turned west, leaving the bones of their ancestors to keep watch in old familiar neighborhoods while they began over again where lands were fresh and cheap and debts were no disgrace.

"Such a system, of necessity, ran its course in the older regions well before the American Revolution. Many planters turned farmer, dividing their lands and labor forces into smaller units, shifting production to wheat and corn, and seeking markets that lay outside the grip of the British merchant and his much despised Scotch agents. But the Revolution interrupted adjustments, adding its ruin to an already bad situation, which did not greatly improve for the masses until the French Revolution and its spread gave to the American farmers the profitable task of furnishing food to those whose efforts were absorbed by war. A few great planters, such as Washington, Jefferson, and Madison, led the way to changes for the better conservation of the soil, while such specialists as John Binns and John Taylor of Caroline preached a new gospel of fertilizers and crop rotation which would have altered fundamentally the whole agricultural procedure. But uncertain profits checked wide change, and the Peace of Ghent threw the whole old tobacco world back in ruins, sighing 'for another Napoleon to restore to us by his wars the feeding of Europe.'

"Thus, when Edmund Ruffin, just turned nineteen, took over the responsibilities of a planter on weary lands, the situation represented the accumulations of two centuries of bad methods. Plows and plowing were poor. Iron moldboards were just coming into use, but the great majority, suspicious of anything new, preferred to go on with their old implements, cutting shallow furrows up and down the hillsides to become veritable watercourses of destruction in time of rains. Furthermore, the rotation of crops, though followed by a few, met serious difficulties in the failure of clover or other legumes to grow on poor lands, which cut the supply of livestock and manure and precluded the profits that would have made possible the purchase of artificial fertilizers. Slaves multiplied out of proportion to agricultural needs, becoming a burden on masters and fields until the strong paternal sense which characterized the institution in this region weakened to permit the sale of the human surplus into the spreading cotton fields of the 'Lower South.' Tattered and briary, the lands lapsed back to become the haunts of deer and wild turkey, while stolid men and patient women plodded on with a persistence too mechanical to have been born of courage. Agriculture was steadily yielding ground in both a real and a figurative sense.

"Travelers and natives alike in this period (1815–1830) agree on the impression that an 'angel of desolation had cursed the land,' many tracts presenting scenes of ruin 'that baffle description—farm after farm . . . worn out, washed and gullied, so that scarcely an acre could be found in a place fit for cultivation;' 'dreary and uncultivated wastes, a barren and exhausted soil, half clothed negroes, lean and hungry stock, a puny race of horses, a scarcity of provender, houses falling to decay, and fences wind shaken and dilapidated.'

"Meanwhile 'an emigrating contagion resembling an epidemic disease' had seized the people. 'Thousands . . . in the hopelessness of bettering their condition in their native land' abandoned 'the beloved homes of their nativity.' The rate of population growth in Virginia fell from thirty-seven and a half per cent in 1820 to thirteen and a half per cent in 1830 and then to only a trifle over two per cent in the next decade. Many counties lost population, and there were over 388,000 Virginians in other states in 1850. Ruffin himself later declared: 'There was scarcely

a proprietor in my neighborhood . . . who did not desire to sell his land, and who was prevented only by the impossibility of finding a purchaser, unless at half of the then very low estimated value. All wished to sell, none to buy.' And what was true of lower Virginia applied with equal force to the older portions of Maryland and the Carolinas. The prospects for a young planter were, indeed, gloomy.

"With an enthusiasm born of youth and theories developed from childhood reading, Ruffin assumed his task. His lands at Coggin's Point were extremely poor, 'the larger part not averaging more than ten bushels of corn per acre, no more than six bushels of wheat, on the better half.' From experiment to experiment he moved, failure dogging his steps. He drained his better swamp lands only to find their yields, after three years of good crops, so reduced as to necessitate abandonment. He turned to John Taylor's much discussed system of 'enclosing,' receiving 'as sound and true every opinion and precept,' but ended in 'utter disappointment.' The manure he applied 'produced little of the expected effect on the first course of crops and was scarcely to be perceived on the second.' Clover would not grow for him, and 'the plowing on hilly land . . . into ridges, caused the most destructive washing away of soil by heavy rains.' After four or five years of trial Taylor's methods 'proved either profitless, entirely useless or absolutely and in some cases greatly injurious.' He was forced to admit that no part of his 'poor land was more productive than when . . . (his) labors commenced and that on much of it, a tenfold increase had been made of the previously large space of galled and gullied hillsides and slopes.'

"Old residents, grown weary in the struggle, had long since concluded that lands in this part of the state could not hold manure or be enriched. They smiled in tolerance as the young theorist continued to reject this 'monstrous agricultural heresy' but did not withhold the 'I told you so' when at last he too 'was compelled, most reluctantly, to concur in this opinion.' He had failed. He would seek 'the rich western wilderness' where his 'whole income and more' would not be required for the most economical support of his 'small but fast growing family.' Not the lure of verdant fields in Kentucky or Alabama stirred him, but benumbing pressure weighing heavily on one who thought of the future in terms of children and even slaves who must have the things that a gentleman gives to his dependents."

In such a frame of mind Ruffin had the good fortune of having a copy of Davy's *Agricultural Chemistry*, first published in 1813, fall into his hands. It was probably more than mere chance that this happened, for Ruffin, in his intense zeal to find some solution to the baffling problems of soil management that faced him, was apparently combing all available sources of information. Although Ruffin states that his limited knowledge of chemistry was obtained without aid or instruction, his keen, analytical mind apparently made it possible for him to master the contents of Davy's book in short order. His attention was particularly attracted to a statement to the effect that a sterile soil containing "the salt of iron, or any acid matter. . . . may be ameliorated by the application of quicklime."

In Davy's book he found directions for testing soils for soluble iron, calcium, and calcareous earth and also testing limestone and marl for their carbonate content. Ruffin immediately assembled the necessary equipment and chemicals for making these tests. Although he was not able to reveal the presence of free acids in his soil, he did show that carbonates were absent, and having observed that sorrel and pine

abounded on poor soil, he was led to the independent conclusion that "vegetable acids" were the cause of sterility in his soils. Ruffin was thus probably the first man in the whole world to conclude that upland mineral soils are often acid due to the presence of free acids, made possible by the absence of calcareous earths. In defense of this conclusion, he presented arguments which were in advance of some presented by trained chemists nearly a century later. He observed for example, that drainage waters from non-calcareous soils are often darker in color than those from calcareous soils, due, he contended, to the solubility of the free organic acids and insolubility of the lime salts of these acids. He also held that all fertile soils are either calcareous or hold lime in combination with acids in such form that it is easily extracted with hydrochloric acid. The thoroughness of Ruffin's consideration of the subject is evidenced by his detailed reference to the work on humic acids which Berzelius was doing at about that time. He also refers to the work of Sprengel and others.

Although litmus paper was used by the chemist as early as 1807 to detect acidity and alkalinity in the laboratory[4], yet Davy makes no mention of its use in testing soils. The earliest references to the use of litmus paper for testing the reaction of soils that the writer has traced are one by Thaer[5] in 1856 and one by Voelcker[6] in 1865. One can well imagine the thrill Ruffin would have experienced had the litmus paper test been available to him so that he might have given positive demonstration of the general prevalence of acidity in upland mineral soils of the humid region. At any rate, his conclusion that upland mineral soils are often quite sterile due to an acid condition was essentially true. With the aid of the test for carbonates, Ruffin located deposits of marl on his farm and at other places in the neighborhood. He now decided to make an actual test of his theory. Quoting again from Avery, page 55:

"On a February morning in 1818 his carts began to haul the marl that puzzled negro hands dug from pits hastily opened on his lower lands. They spread some two hundred bushels over a few acres of newly-cleared, but poor, ridge land, and in the spring he planted the entire field to corn as a testing crop. Eagerly he waited. As the season advanced, he found reason for joy. From the very start the plants on marled ground showed marked superiority, and at harvest time they yielded an advantage of fully forty per cent. The carts went back to the pits. Fields took on fresh life. A new era in the agricultural history of the region had dawned.

"With all the ardor of a discoverer Ruffin immediately set about to widen his knowledge by extended experiments and to spread the information which offered so much to his fellow planters and to his section. In October of that year he presented to the agricultural society of his own county the first of what was to be a long list of valuable papers offered to the cause of agriculture. Stating his theories as 'to the nature of soils and the action of calcareous manures' on them, he adduced the slender sum of his experience to support what was, in fact, a revolutionary approach to the whole problem that vexed the farmers of the New World. While the great rural hosts, facing westward, moved steadily forward to the ex-

[4]Die Apotheker-Kunst, von Trommsdorff. 1807.
[5]Principles of Agriculture, page 184, New York. 1856.
[6]Jour. Roy. Agr. Soc., 1 (2 Ser.): 113–130. 1865.

ploitation of a continent's virgin fertility in the name of progress, he offered a new program of restoration which had as its purpose an 'about face' induced by the creation of opportunity in the lands of the older regions. He would save the Old South. He would commit that greatest of all agricultural crimes—he would rely on theory and books!"

In the language of my address tonight, he would put soil science to work. Quoting further from Avery, page 56:

"Three years later this paper, revised and enlarged, was published in the *American Farmer*, the new agricultural journal that John Skinner had started in Baltimore. The editor hailed it as 'the first systematic attempt . . . wherein a plain, practical, unpretending farmer has undertaken to examine into the real composition of the soils which he possesses and has to cultivate. So fundamental did he consider the contribution that an extra edition of this issue was printed to be distributed gratuitously to the farmers of the country. Eleven years later, grown into a volume of 242 pages, it appeared again under the title, AN ESSAY ON CALCAREOUS MANURES, to run through five editions and to be called at the end of the nineteenth century by a government expert, writing in the YEAR BOOK OF THE UNITED STATES DEPARTMENT OF AGRICULTURE, the most thorough piece of work on a special agricultural subject ever published in the English language. Contemporary writers, who have been lifting their jeremiads amid the agricultural ruins and 'the draining off of our most independent citizens to the West,' hailed him as a deliverer, taking rank at once with the great John Taylor of Caroline whose ARATOR had been the first cry in the wilderness. Even the doors of politics swung open to him, and in time a president of the United States would declare that his ESSAY 'in its valuable consequences' would 'be worth more to the country than all the state papers that have been the most celebrated in our time.' Over John Tyler's mantel Edmund Ruffin's portrait would hang as a companion piece to that of Daniel Webster—the greatest American agriculturist and the greatest American statesman!"

In the light of this rather extended review of Edmund Ruffin's work relative to scientific and practical soil management, I think you will all agree that Edmund Ruffin, as Craven says, "has good claim to be called the father of soil chemistry in America". Some of you have read George Washington's difficulties in the culture of alfalfa and, even, clover. Washington was thoroughly familiar with the agricultural writings of the foremost authorities in England of his time. He was, in fact, in regular communication with no lesser authority than Arthur Young. It was impossible, however, for Washington to obtain much aid, even from the foremost authorities, because soil chemistry was just being born at the time of his death in 1799. Davy's writings on agricultural chemistry had, as yet, not appeared.

Washington practiced erosion control to some extent, took special pains to conserve animal manure, went to great labor in fertilizing with mud obtained from creeks and marshes, and spent much money in the purchase of special seeds, nevertheless, he was unable to materially increase production or even maintain the level of soil fertility. Had he known that his soil was acid and needed lime (the U. S. Soil Survey map shows that the crop lands of Washington's Mount Vernon

Farms consist largely of Keyport silt loam which lacks lime even under virgin conditions), he undoubtedly would have applied the lime, and then clover and even alfalfa would have grown so that the nitrogen and organic matter supply of his land might have been maintained or increased. The use of lime would probably have deferred the advent of failing crops by 25 to 50 years, that is, until phosphorus and potassium became limiting elements. The agricultural situation in 1834, 35 years after Washington's death is expressed by Craven (page 63) as follows:

> "By 1834 a visitor to 'Mount Vernon,' where the great Washington had struggled for better methods, declared that 'a more wide-spread and perfect agricultural ruin could not be imagined.' Jefferson at 'Monticello' was closing his days in poverty as his fields and markets failed him; everywhere the agricultural societies dwindled for lack of support as farmers lost heart; and even John Binns and his gypsum yielded ground."

In order that he might give his discoveries relative to the use of lime greater publicity, and that better methods in agriculture might be promoted, Ruffin in 1833 launched his agricultural periodical called the *Farmers' Register*. This publication was called by John Skinner, a prominent editor, to be the "best publication on agriculture which this country or Europe has ever produced."

Ruffin also purchased another estate of nearly 1000 acres of choice land in Hanover County, Virginia, which he appropriately called "Marlbourne". He had no sooner moved to this new estate in 1843, when he set to marling 800 acres or more in preparation for clover. He installed a system of drainage, gave most careful attention to the preservation and use of barnyard manure, and persisted with his trials until clover grew too rank for his machines to cut. The results of scientific farming were soon manifest, for in the period 1845 to 1848, his yields per acre of wheat increased from 15 to 20 bushels, and corn from 14 to 29 bushels. His profits on wheat alone for one year were nearly $6,000.

I would not have you believe that Ruffin was the first man in America to use lime for we have definite reference that liming of land was practiced to some extent in Colonial days, particularly in Pennsylvania and New Jersey. As is well known, history records definitely that liming of land was practiced long before the Christian Era. Undoubtedly here and there long before the dawn of history, man scattered ashes from his fire or marl from the pit, over land which he later planted to crops and noted marked improvement in his harvest therefrom. At another time and place he repeated the practice but the results were not favorable. He knew not why for his results were empirical and there was no soil science which might be put to work. Thus he dropped the practice as did others that followed him. By the time of the Romans, however, there had accumulated a sufficient body of favorable results from the liming of land that their writers on agriculture were disposed to give the matter considerable prominence. In Britain, the liming of land may have antidated the invasion by the Romans, since lime in the form of chalk and marl is there so plentiful. Hall states "The regular use of some form of lime or chalk

was part of the accepted routine of farming as early as we possess any records of British agriculture, and among the manures it figures in all books of the 16th and 17th centuries."

While the practice of liming land probably antidates all records of the practice, nevertheless the idea that an acid condition of the soil is the principle factor involved in the liming of land is of rather recent origin. The early English writers, including Davy, ascribed the main benefits of liming land to its influence on the physical condition of the soil, while Leibig attributed the benefits more to the liberation of alkalies and silica from silicates. In 1849 a most excellent treatise by Johnston on liming of soils made its appearance in Britain. As far as the writer has been able to determine, this is the first time that some other writer than Ruffin has given considerable prominence to the action of lime in neutralizing soil acids.

During the last 15 to 20 years of his life, Edmund Ruffin spent much of his time in the discussion of political and economic problems. He was a strong advocate of slavery and fired the first gun at Fort Sumter which precipitated the Civil War. He took an active part in several battles of the Civil War, and shortly after Lee's surrender, at the age of 71, feeling that he was now a man without a country, and too old and weary to be other than a burden to his children, he with stern logic, caused a shot to ring out in order that he might join his comrades who died in battle for a lost cause.

Unfortunately, due to the confusion and disorganization wrought by the Civil War, Ruffin's writings relative to the use of calcareous manures were largely forgotten and lost. The practice of liming, as far as the South is concerned, seems to have largely ended for the time being with the passing of Ruffin. It remained for H. J. Wheeler in the closing years of the 19th century to revive the idea of the general prevalence of acidity in upland mineral soils. By this time, the use of litmus paper for the testing of soils had come into use, and Wheeler, by means of this test, was able to demonstrate positively that many upland mineral soils are distinctly acid and need lime. This was the beginning of a sustained appreciation in this country of the need and value of lime in agriculture.

Over 100 years have passed since Edmund Ruffin through painstaking work and brilliant scientific achievement concluded that upland mineral soils in the humid region often need lime because they are acid, and nearly 50 years have passed since H. J. Wheeler gave positive demonstration to the general prevalence of soil acidity in upland mineral soils of the humid region, and still today, we are applying only a small fraction of the lime to soils that we should. Moreover, today we have tests of considerable refinement for determining the lime needs of soils; lime or marl has been located in nearly every section of the country where liming is needed; highly efficient machinery has been devised for grinding limestone and digging marl; power for operating this machinery is abundant, facilities for transporting the lime to the farm where needed have been developed beyond the fondest hopes of 25 years ago; and finally we have data almost without end showing that the use of lime is fundamental in the humid region to the growth of legumes to nitrogen fixation, to a

favorable availability of soil phosphates, and finally to soil conservation itself. We ride about the country and pass through sections where the eye meets out-crops of limestone in every direction, but alas, due principally to an acid condition of the soil, there are no fields of alfalfa, sweet clover, or other high grade legumes which are so necessary for the creation of a land of "milk and honey".

What is the answer to our dilemma? In a recent article the speaker wrote as follows:[7]

> Why did Kentucky, in 1936, use the equivalent of 124 pounds of lime oxide per acre of crop land and Tennessee only 8½ pounds, and similarly, in the same year, Wisconsin 64 pounds and Michigan only 14 pounds? The climate, need of lime, and natural supplies of lime in the pairs of States compared are quite similar. All of these States have extension services which for a long time have been offering information on the subject through demonstrations, publications, and lectures. Evidently that method alone will not do the job. Until the extension services are able to form some connection with a large-scale organization, either private or governmental, that can be depended upon to furnish the farmer this basic and fundamental soil-building material—lime—at a reasonably low price, or some other equally effective method is found and adopted, permanent soil improvement and soil conservation will remain, to a large degree, "a pot of gold at the end of the rainbow".

Cheap lime for short periods made possible by emergency measures will alone, however, not bring about permanently the kind of a liming program that is needed. The agronomists must do their part. The agronomists must take a positive stand. The agronomists must put soil science to work. They must speak in terms of the general rule rather than in terms of the exception. Too often in the past when the farmer has asked—point blank—"will it pay me to use lime?", the agronomist has retreated to his first-line trenches consisting of a camouflage of garbled scientific or other high-sounding "triple-threat" words, something like this—"Well, you know the soil is a complicated physico-chemico-biologico system made up of mineral and organic material some of which is in colloidal condition, and all of which is infested or populated with myriads of both beneficial and detrimental organisms too small to see. Just what lime will do to these colloids and organisms, I am not quite sure. It might cause what the soil biologist now calls 'a sit down strike' on the part of the organisms, or what the soil chemist calls 'a slow-up strike' on the part of the soil colloids. I tell you what you do. Get a few bushels of lime and spread it on a few square rods of your field, and then if the crop increase is sufficient to pay for the lime and leave a profit, then it will pay you to use lime."

After the agronomist has effected this retreat, what does the farmer do? He also retreats and does exactly what you would do under similar circumstances, namely, he does as in the past, he does not use lime.

How should the agronomist meet a situation fraught with a few special or exceptional cases? Here is Ruffin's answer:[8]

[7] U. S. Yearbook of Agriculture, page 564. 1938.
[8] Calcareous Manures, ed. 2, page 53. 1832.

"There are many practices universally admitted to be beneficial—yet there are none, which are not found sometimes, useless or hurtful, on account of some other attendant circumstance, which was not expected, and perhaps not discovered. Every application of calcareous manures to soil, is a chemical operation on a great scale: decompositions and new combinations are produced, and in a manner generally conforming to the operators expectations. But other and unknown agents may sometimes have a share in the process, and thus cause unlooked for results. Such differences between practice and theory have sometimes occurred in my use of calcareous manures (as may be observed in some of the reported experiments) but they have neither been frequent, uniform, nor important."

And again quoting from Avery, page 63, here is a sample of what Ruffin accomplished 100 years ago, without any expense to the taxpayer, by preaching the philosophy of the rule rather than the philosophy of the exception.

. . "From 1838 to 1850 the land values of tidewater Virginia increased by over seventeen millions of dollars, and one estimate placed the total increase from the application of marl, after 1820, at over thirty millions. One writer, evidently carried away by his own eloquence, declared that 'Mother earth has changed her face, and . . . her constitution under the healing influence of this salutary medicament, and now presents an appearance as different from her former self, as the healthy and robust man from the lingering and hectic victim of consumption.' 'Verdant fields,' 'luxuriant clover,' and 'abundant harvests' had taken the place of 'broomstraw and poverty grass,' while a poor, thin, and stunted vegetation had 'disappeared.'"

Farmers and even agronomists often say that liming of land is too expensive. Well, how expensive is it? Since a ton of ground limestone, costing in some North Central States approximately $2 will balance this loss for a period of 5 to 10 years, the annual cost per acre becomes 20 to 40 cents. Data from experiments and demonstrations are at hand, almost without end, showing that this cost is insignificant compared to the increased production and the soil improvement that result.

And here again is what Ruffin says relative to the cost of liming land:[9]

"We never calculate the cost of any old practice. We are content to clear woodland that afterwards will not pay for the expense of tillage . . . But let any new practice be proposed, and then every one begins to count its cost—and on such erroneous premises, that if applied to every kind of farm labor, the estimate would prove that the most fertile land known, could scarcely defray the expenses of its cultivation."

In developing the subject of my talk this evening, I have spoken largely of matters pertaining to liming of land. This method of approach was adopted because that phase of the subject has the richest historical background. What has just been said relative to the agronomists duty in promoting the use of lime applies also to the use of fertilizers, to the furthering of soil conservation, and the adoption of

[9]*Ibid*, page 61.

proper land use programs. We agronomists must all adopt a more incisive and positive attitude in promoting sound and practical programs of soil management.

Before closing, I wish to speak of one more phase of the subject, namely, that having to do with soil testing and the use of fertilizers. I believe it is safe to say that soil and lime testing, crude as it was, is what made possible Ruffin's monumental work in the field of soil acidity, liming, and soil management. During the early years of the 19th century, soil testing was well on its way to becoming a powerful tool in diagnosing the needs of sick soils, as is evidenced by the following quotations:

In 1813, Sir Humphry Davy wrote in his "Elements of Agricultural Chemistry", as follows:

> "If land be unproductive, and a system of ameliorating it is to be attempted, the sure method of obtaining the object is by determining the cause of its sterility, which must necessarily depend upon some defect in the constitution of the soil, which may be easily discovered by chemical analysis."

Fifty-two years later, Dr. August Voelcker[10] wrote as follows:

> "There was a time when I thought, with many other young chemists, that soil-analyses would do everything for the farmer, three or four years of further experience and hard study rather inclined me to side with those men who consider that they are of no practical utility whatever; and now, after eighteen years of continued occupation with chemico-agricultural pursuits and, I trust, with more matured judgment, I have come to the conclusion that there is hardly any subject so full of practical interest to the farmer as that of the chemistry of soils,—the longer and more minutely soil-investigations are carried on by competent men, the greater, I am convinced, will be their practical utility."

Following these early successful attempts at soil testing, there developed during the latter years of the 19th century, a school of thought which held that practically no information of value relative to the lime and fertilizer needs of a soil can be obtained by means of soils tests. This thought arose largely, I believe, because too much was expected at once of a tool in its early years of development, when too little was known of the forms in which plant nutrients exist in soils, of how the readily available constituents may be extracted and determined easily, and finally of the influence of secondary factors such as the minor plant nutrients. Unfortunately this thought still persists in the minds of many agronomists. If soil testing was practicable in Davy's, Ruffin's, and Voelcker's time, it should be even more practicable today when so much more is known relative to the many factors involved.

Following the abandonment of soil testing, for the most part, there developed a mania during the first quarter of the 20th century for the establishment of long-time field experiments. The speaker would not have you think that he does not believe in field experiments and field demonstrations. These field experiments are useful and necessary in establishing sound general principles of soil management. That is, principles, which can only be established by noting the

[10]See footnote 6, page 129.

influence of specific treatments over a long period of years. They are not adapted, however, for determining the lime and fertilizer needs of a specific soil because these needs vary from field to field on the same farm and even in different parts of the same field. Many field demonstrations are of course needed to help convince farmers of the value of certain practices.

I do not wish to leave the impression that I believe chemical soil tests are infallible. They are, of course, not. However, after 25 years of continuous experience with soil tests, I am convinced that with further study and improvement they will in time be generally used by all agronomists in diagnosing the lime and fertilizer needs of soils devoted to practical agriculture. I envisage a time in the near future when conditions and the supply of plant nutrients in soils devoted to intensive culture will be controlled by means of tests, much like similar matters are controlled in a chemical factory. Then, and only then, can we say that we are putting chemical soil science fully to work in a practical way. In the case of long-time field experiments, soil tests should be applied, from time to time, to determine the influence of any specific treatment on the level of fertility. The results of these soil tests may in certain cases suggest a change in the rate of lime or fertilizer application so as to keep the experiment on a practical basis. Similarly, in practical farming, soil tests serve as an indispensable guide in telling whether or not the returns to a soil are meeting the removal under a specific system of fertilization and cropping.

Some agronomists become greatly disturbed when fertilizer applied on the basis of soil tests does not give sufficient crop increase the first year to pay for the fertilizer. They seem to forget the all-important long time benefit, namely, that of maintenance of soil fertility which is the backbone of soil conservation, for, fertile soils soon produce a protective cover of vegetation, which, for the most part, is the best preventive of soil erosion.

It is the duty of all agronomists to preach the doctrine that the major plant nutrient elements removed from the soil by crops must be returned, pound for pound, in the form of crop residues, animal manure, or commercial fertilizers, if soil fertility is to be maintained. Any other policy has in the past led to and will in the future lead to, first, soil depletion, then, soil destruction by erosion, and finally, economic ruin. To take more out of a soil than is returned, is as certain to deplete a soil in time as the removal of money from a checking account at a greater rate than its return is of putting the checking account "in the red".

Can farmers be sold on the philosophy of returning as much to the soil as is removed? This philosophy is so simple and so sound that farmers can be induced to accept it more easily than some of the make-shift or stop-gap philosophies. During the early years of the present century, Dr. C. G. Hopkins of Illinois preached this philosophy in a positive manner, and, in a short time, sold it so thoroughly that today, 20 years after his passing, many farmers because of his personal influence are still following it.

In general, what policy do many agronomists follow relative to this matter? I size it up about as follows: As long as crop yields are

fairly good and lime and fertilizer do not produce striking results, the farmer is told that the addition of lime and fertilizer is not urgent or needed. Thereupon the farmer spends his spare cash for farm machinery, automobiles, and even speculative securities. Time moves on, and crop yields decline, as they must, and reach a lower than cost of production level, even before the arrival of the impending economic depression. Then the depression breaks with all of its fury, and the farmer aged and weary retires and bequeaths to his son the farm, but, without the soil, without any capital, and without a legacy of information and training relative to maintenance of soil fertility and soil conservation. Under these circumstances, only an Edmund Ruffin succeeds. Unfortunately, Edmund Ruffins are not born everyday, and thus, in many cases it becomes necessary for the government to rehabilitate both the farm and the farmer.

Will this cycle of soil depletion and agricultural desolation be repeated, over and over, indefinitely? If the answer is to be no, then it will be necessary for the agronomist not only to take soil science from the sequestered cloister of the laboratory and hitch it to the plow, but also to go forth preaching a positive and realistic program of soil management and conservation as Edmund Ruffin did over 100 years ago.

(N.B. In view of requests from several sources for an opportunity to obtain a supply of reprints of this paper, the type will be held until about January 15. Orders should be placed with the Editor as soon as possible.)

THE UTILIZATION OF WATER BY ALFALFA (*MEDICAGO SATIVA*) AND BY BLUEGRASS (*POA PRATENSIS*) IN RELATION TO MANAGERIAL TREATMENTS[1]

V. G. SPRAGUE AND L. F. GRABER[2]

THE responses of alfalfa and bluegrass to deficits in rainfall are highly variable under field conditions. Differences in soil fertility, topography, exposure, evaporational losses, and other interacting factors, cause some bluegrass pastures to remain green much longer during periods of drought than others immediately adjacent. From field observations it would appear that differences in grazing management also may be a highly significant cause of such variations.

The stage of growth at which alfalfa is cut during periods of drought may hasten or retard recovery. In dry seasons, cutting at the early bud stage will usually provide a more immediate recovery than a cutting delayed until near the full bloom stage. However, when drought continues, the more immediate resumption of the growth of alfalfa with early cutting is not usually of practical significance. Moreover, with ample rainfall after cutting at or near full bloom recovery is prompt, except for some varieties of inherent slow recovery such as the Ladak, and the growth is usually more productive in Wisconsin, as recently reported by Graber and Sprague (4).[3]

The purpose of this experiment has been to determine if such variable field responses of bluegrass and alfalfa to moisture deficits may be, in part, a matter of difference in water utilization resulting from variations in managerial treatments of top growth and variations in nutritional levels. The designation "water requirement" as used in this paper refers to the ratio of the amount of water utilized by a plant to the dry matter produced by the plant exclusive of the subterranean parts.

REVIEW OF LITERATURE

Much experimental work has been done on water utilization of plants. As early as 1850, Lawes (7) first demonstrated the effect of fertilizers in lowering the water requirements of plants. Later, Wilfarth and Wimmer (15), Wimmer (16), Widstoe (14), and Leather (8) obtained similar results. Kiesselbach (6) reported in 1916 that while the total water utilized by corn increased 106.7% with increasing levels of fertility, the water requirement of the plants decreased 42.6%. On the basis of the accumulative increments in units of dry matter, water was used more efficiently by plants grown on soils with higher fertility levels.

Some of the evidence on water utilization is rather conflicting. Von Seelhorst (12) in 1910, working with grasses, showed that the water requirement of cultures harvested four times during the summer months was greater than those harvested three times. More recently, Schwarz (11), after a study of the water requirement

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[3]Figures in parenthesis refer to "Literature Cited", p. 996.

of several grasses, concluded that increased yields, in general, were associated with increased utilization of water but with a decreased water requirement and that the date of cutting played a decided rôle in the economy of water.

Richardson and Trumble (10), working with several pasture plants, reported in 1936 that fertilizers, including nitrogen and phosphorus, decreased the transpiration ratio by increasing the dry matter yield of plants and that defoliation either decreased the transpiration ratio or made no change in it.

Briggs and Shantz (1) measured the water utilization of Grimm alfalfa at Akron, Colorado, during three periods, *viz.*, May 24 to July 26, July 26 to September 6, and September 6 to November 4, 1912, the second period being the hottest part of the growing season. One series of alfalfa was cut three times at hay stages, once on July 26, once on September 6, and once on November 4. The water requirement was 600 for the first period, 853 for the second period, and 421 for the third period. The other series was cut three times on the same dates but during the second period the alfalfa was given five additional clippings on August 3, 10, 17, 24, and 31 to simulate grazing during hot weather. With this treatment the water requirement was 615 for the first period, 975 for the second period, and 479 for the third period. Under both treatments there was a marked rise in the water requirement of the alfalfa during the hot period, although the rise was less with the alfalfa clipped frequently.

Dillman (3) conducted very extensive trials (1912–22) on the water utilization of a large number of agronomic plants under conditions of the region of the Northern Great Plains. He found a wide range in the water requirements of different species varying from 224 for Russian thistle (*Salsola* spp.) to 1,183 for western wheat grass (*Agropyron* spp.). There was considerable variability in the water requirements of a given species, dependent upon seasonal conditions. For example, with Kubanka (Durum) wheat, the water requirements were low when the evaporational rate was low and the moisture supply was abundant; and conversely, when the water supply was low and the evaporational rate was high, the yields were small and the water requirements were high. Dillman found that the rate of water utilization increased rapidly as the plants reached their maximum growth and that field crops use very little water during their early stages of growth. When Grimm alfalfa was cut twice after it had matured seed, the water requirement was 28% greater than if cut twice in the early bloom stage of growth and when cut more frequently at intervals of two weeks the water requirement was still further reduced.

The influence of rust diseases on the water economy of cereals has been studied by such workers as Murphy (9), Bever (2), Weiss (13), and Johnston and Miller (5). In general, they have found marked increases in the water requirements of infected plants and that the longer the period of association of host and parasite, the greater was the increase in the water requirement of the host plant.

EXPERIMENTAL PROCEDURE

To study water utilization from the standpoint of management and nutritional treatments, pure cultures were used of two of Wisconsin's most important forage plants—alfalfa (*Medicago sativa*), which is primarily used for hay but is fast becoming increasingly important as dry-weather pasture, and Kentucky bluegrass (*Poa pratensis*), the dominant species of the permanent pasture area.

The trials were conducted in a greenhouse at Madison, Wisconsin. All plants were grown in iron boxes 6 x 8 inches and 12 inches deep filled with a weighed

amount of soil composited from two-thirds Miami silt loam and one-third quartz sand which were well mixed with enough lime, phosphate, and potash added to provide an optimum status of mineral nutrition. On September 8, 1934, seven months before the actual treatments were begun, 96 six-months-old high carbohydrate Turkistan alfalfa plants were dug from the field. The tops were trimmed to 1 inch above the crown and the roots were cut to a uniform length of 6 inches before transplanting four into each of the containers. These boxes were fitted with galvanized iron covers which lay tightly against the soil. Four holes 1½ inches in diameter were cut in each cover where the alfalfa roots were transplanted. The space around the roots was covered with soft wax and the joints at the edges of the iron cover and box were also sealed.

On the same date six vigorous rhizomes of Kentucky bluegrass trimmed to include four nodes were transplanted from the field into each of 24 similar boxes. The soil surface was covered with sheet iron similar to the alfalfa series except that three rectangular openings 1 x 6 inches were cut in the covers. The rhizomes were planted in the soil beneath these openings. The iron cover was sealed with soft wax only around the edges of the containers. The rectangular openings were left uncovered. The amount of water lost from these exposed soil surfaces by evaporation was not determined but due consideration for such errors in the bluegrass cultures will be given in the interpretation of the results.

Water was introduced into each culture by means of L-shaped ¾-inch glass tubes with numerous holes blown through the sides. They extended to the bottom of the iron container where a layer of quartz sand had been provided for a uniform distribution of water throughout the culture. Before transplanting, the containers with soil, sand, and glass tubes were weighed individually and 700 cc of water were added. This provided a moist soil with about 18% moisture which was estimated to be about optimum for the growth of the plants. Each culture weighed approximately 14 kg when ready to be planted. An attempt was made to maintain the water content of the soil at an optimum for the growth of the plants by weighing the cultures every one or two days to make certain all cultures were equally well supplied with water. Even though the area for subterranean growth was limited the plants had full opportunity to grow without the stress of moisture deficits. A fairly uniform distribution of roots in the soil at the close of the experiment indicated that the moisture had not been unduly localized.

Both alfalfa and bluegrass cultures were given favorable conditions to establish themselves for 7 months (after September 8) during fall, winter, and early spring. The top growth of all the cultures was cut down to a ½-inch level on April 9 and the various cutting and fertility treatments were begun at this time.

The experiment included a high-carbohydrate (+CHO) series, simulating deferred grazing or cutting, and a low-carbohydrate (—CHO) series simulating close continuous grazing, in combination with a high-nitrogen (+N) series and a low-nitrogen (—N) series. Each treatment applied to the alfalfa and to the bluegrass was replicated with six cultures. The variable factors may be outlined schematically as follows:

Alfalfa	+CHO	+N	Kentucky bluegrass	+CHO	+N
		—N			—N
	—CHO	+N		—CHO	+N
		—N			—N

The +N treatments were effected by three applications of ammonium nitrate in solution on April 2 and 16 and on May 4 at the rate of 70 pounds of N_2 per acre for each application. The —N cultures received no nitrogen fertilizer. On April 23, 600 pounds per acre of monocalcium phosphate ($CaHPO_4$) and 300 pounds per acre of potassium sulfate (K_2SO_4) were added in water solution to all cultures in the experiment to make certain that a lack of phosphate and potash would not limit growth.

The alfalfa plants and the rhizomes of bluegrass taken from the field and transplanted on September 8 made a healthy vigorous growth becoming well rooted with large accumulations of reserve foods after 7 months of uninterrupted growth. At the end of the period (April 9) the alfalfa was in full bloom and the bluegrass had produced a dense growth of long dark green leaves with all the external evidence of ample food storage. On April 9, the top growth of all cultures was removed at a ½-inch level from the soil surface.

To simulate a deferred grazing plan, cultures of alfalfa and bluegrass were allowed to grow for 65 days (from April 9 to June 13) without cutting. During the early part of this period the plants grew in part at the expense of previously stored foods, but during the latter portion of the period reserve foods accumulated in great abundance, therefore, they shall be referred to as the high-reserve (+CHO) cultures. Half of these cultures (+N) were given three applications of ammonium nitrate (NH_4NO_3) at the rate of 70 pounds of N_2 per acre each and the remainder were not fertilized.

To simulate continuous grazing (—CHO), portions of the top growth were removed at weekly intervals from April 9 to June 13. The bluegrass was cut back to a ½-inch level above the soil surface and the alfalfa was removed at about 2½ inches above the soil surface, a taller remnant of the photosynthetic area being required to avoid a lethal degree of reduction of reserve foods than of bluegrass.

The cutting treatments of both the alfalfa and bluegrass were carried on in two periods. During the first period, from April 9 to June 13, the water utilized and the dry matter (oven-dry basis) produced with weekly clippings of plants high in reserves and grown under high and low nitrogen supplies were recorded. Similar records were taken on the series which was not cut until June 13. This made it possible to compare the water utilized and dry matter produced under the two levels of nitrogen with two cutting treatments.

The second period was that of recovery. It extended from June 14 to July 18 (35 days) during which time all the plants of bluegrass and alfalfa were allowed to grow without cutting or other treatments until July 18. A measure of water utilized and the dry matter produced during this period provided a measure of the residual effects of the previous cutting and fertility treatments on water utilization.

DAILY RATES OF WATER UTILIZATION IN RELATION TO TOP GROWTH

The daily use of water by alfalfa from April 9 to June 13 varied widely in accordance with accumulations of top growth. All cultures responded, more or less, to variable temperature and light conditions in the greenhouse, but such responses were not studied. Where the top growth was not interrupted by cuttings (+CHO) the water utilization was low, ranging between 119 and 200 grams per day (Fig. 1) during the early vegetative stages, but increased markedly

from 200 grams to 365 grams per day when the increments of accumulated top growth became very large. With weekly clippings of alfalfa at a 2½-inch level, the daily rate of water utilization was very low (65 to 167 grams) and was rather constant for the entire period of April 9 to June 13, tending only to rise at the forepart of this period and to decline at the latter part. Applications of nitrogen caused but little difference in the daily rate of water utilization with either the high (+CHO) or low (—CHO) reserve treatments of

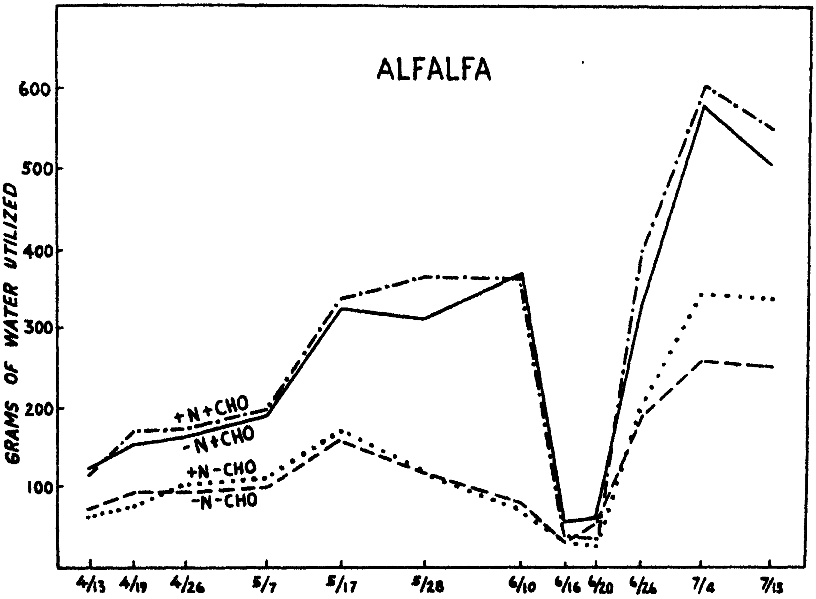

FIG. 1.—Average number of grams of water utilized per day by the alfalfa cultures during the periods represented by their midpoints. All cultures were cut June 13 and allowed to recover without further defoliation. The precipitate reduction in water utilization of the high-reserve plants between the midpoints of June 10 and 16 was due to defoliation on June 13.

alfalfa. Apparently, nitrogen-fixation of the —N alfalfa was sufficient to offset, to a large extent, the influence of nitrogen added in large amounts as ammonium nitrate to the +N cultures.

Nitrogen greatly enhanced the growth of the high-reserve (+CHO) bluegrass and the daily rate of water utilization (Fig. 2) increased from an average of 75 grams in the early vegetative stages to a maximum of 305 grams per day when accumulations of green top growth were greatest. Without nitrogen, the daily rate of water utilization also increased with the increase in photosynthetic area, but the daily rate was much lower and the range (77 to 170 grams) was narrower. Weekly removals of top growth at a ½-inch level not only reduced the daily rate of water utilization still further (53 to 93 grams), but it was quite constant during the entire period of April 9 to June 13. Nitrogen had but very little effect on the daily rate of water utilization of bluegrass given weekly clippings.

TOTAL DRY MATTER PRODUCED AND WATER UTILIZED

The total dry matter (in grams) produced and the total amount of water (in grams) utilized from April 9 to June 13 are given in Table 1. When alfalfa and bluegrass were not cut (+CHO) from April 9 to June 13, the production of dry top growth was much greater and particularly the total amount of water utilized in producing it was much greater than prevailed under the system of weekly cuttings (—CHO).

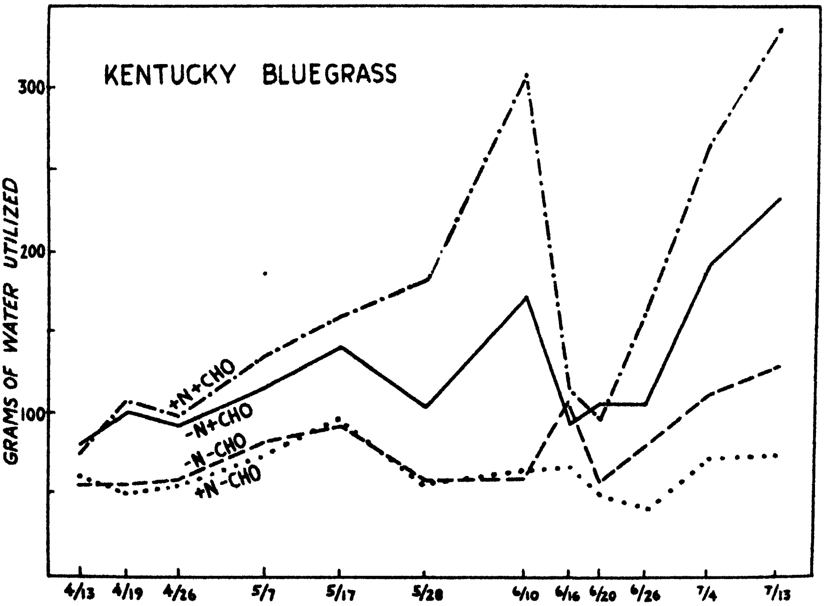

FIG. 2.—Average number of grams of water utilized per day by the Kentucky bluegrass cultures during the periods represented by their midpoints. All cultures were cut June 13 and were allowed to recover without further defoliation. The precipitate reduction in water utilization of high-reserve plants between the midpoints of June 10 and 16 was due to defoliation on June 13.

The ratio between total water consumed and total dry top growth produced for the period of April 9 to June 13 was very much lower with alfalfa clipped frequently (—CHO). The maintenance of a vegetative and succulent growth of alfalfa by clippings at a 2½-inch level lowered the water requirement very materially.

Although the fertilization of alfalfa with nitrogen did not greatly increase the daily rate of water utilization nor the total water utilized, it did lower the water requirements of the high- (+CHO) and low- (—CHO) reserve plants somewhat by increasing the amount of dry matter produced from April 9 to June 13.

Nitrogen fertilization also reduced the water requirement of both the high- (+CHO) and low- (—CHO) reserve bluegrass. It increased the daily rate of water use and the total water utilized of the high- (+CHO) reserve cultures of bluegrass, but the increase in top growth

TABLE 1.—*Total dry matter produced and total water utilized from April 9 to June 13 and from June 14 to July 18.*

Plant	Reserves based on cutting treatments	Nitrogen fertilization	Total H_2O utilized, grams	Total dry matter produced, grams	Ratio H_2O/D.M.
Dry Matter Produced and Water Utilized from April 9 to June 13					
Alfalfa	+CHO	+N	16,267	23.94	679
		—N	15,900	20.62	771
	—CHO	+N	6,767	18.61	364
		—N	6,850	16.91	405
Bluegrass	+CHO	+N	10,533	17.42	605
		—N	7,750	8.65	896
	—CHO	+N	4,466	6.51	686
		—N	4,571	5.76	794
Dry Matter Produced and Water Utilized from June 14 to July 18					
Alfalfa	+CHO	+N	13,583	26.91	505
		—N	12,500	20.56	608
	—CHO	+N	7,883	12.97	608
		—N	6,417	6.97	921
Bluegrass	+CHO	+N	7,716	10.82	713
		—N	5,533	4.06	1,363
	—CHO	+N	2,250	1.16	1,939
		—N	3,400	2.16	1,574

(101%) from fertilization with nitrogen was much greater than the increase (35.9%) in the water utilized to produce it. With the low-reserve (—CHO) cultures, nitrogen fertilization only increased the production of top growth 13%, but the total water utilized was decreased 2.3%.

The weekly clippings (—CHO) of bluegrass at a ½-inch level above the soil surface reduced the food reserves and the productivity of these plants much more than the weekly clippings (—CHO) of alfalfa at a high level of 2½ inches. Thus, weekly clippings (—CHO), from April 9 to June 13, reduced the productivity of fertilized (+N) bluegrass in this period 62% as compared with one cutting (+CHO) on June 13 and 33% as compared with the unfertilized bluegrass (—N). In the case of alfalfa, the concurrent reductions in productivity from weekly clippings were only 22% and 18%, respectively, for the +N and —N cultures.

These and similar comparisons which could be made with respect to subsequent productivity (Table 1) indicate that the reserves of bluegrass were reduced to a much lower status by weekly clippings from April 9 to June 13 than alfalfa clipped at the same frequency but at a much higher level. This matter is discussed because, contrary to the situation with alfalfa, the water requirement of bluegrass was not reduced consistently by the frequent clippings. It appears that the reserves became the limiting factors of growth of the bluegrass and with such and with other limitations of greenhouse culture, the water requirement did not vary widely with respect to the two defoliating treatments (+CHO and —CHO) applied to the bluegrass.

Unfortunately, complete reliance is not to be placed on the data with respect to the water requirements of the clipped (—CHO) bluegrass, since there were unsealed openings in the covers of the bluegrass cultures where the rhizomes were planted and the evaporational losses from these exposed areas were not measured. Perhaps such losses were small and, in some instances, would be comparable, but they would tend to increase the water requirements of the most unproductive (—CHO) cultures. Because the alfalfa cultures were completely sealed, the possibility of such error was eliminated.

WATER UTILIZATION DURING THE FIRST PERIOD OF GROWTH

It would appear from these trials that when alfalfa and bluegrass are kept in a succulent, vegetative state of growth by frequent clippings so that the plastic substances, including previously stored reserves and the immediate photosynthetic products, are being rapidly converted into structural or aplastic materials for growth in expansion, the daily rate of water utilization is relatively low and fairly constant and the total amount of water utilized is greatly reduced. This is much in contrast to the profound increases in daily water use and in total water utilization which prevail when plants approach maturity and accumulate abundant reserves of foods that are stored in the seeds or vegetative parts, or both. With alfalfa, the water requirement was reduced pronouncedly by clippings and conversely it was increased by deferred cutting. Similar results may have been obtained in this trial with bluegrass had it not been clipped so rigorously as to reduce the reserves to a point where they became dominant in the limitation of growth.

It is probable that under field conditions marked accumulations of the top growth of alfalfa and bluegrass resulting from nitrogenous fertilization and from deferred cutting or grazing would greatly increase total water utilization, reducing the reserves of soil moisture as compared with treatments of early and frequent defoliation. Thus, in the advent of drought, alfalfa cut early would have a larger reserve of soil moisture to draw on for prompt recovery and for this same reason bluegrass with early and close grazing could remain green for a longer period during sustained drought. Such field responses have been observed where the differential in moisture supply, due to managerial treatments of the plants, was dominant among other

contributing factors. It is not intended, however, to draw practical conclusions from a greenhouse trial and especially it is not desired to give the impression that early cutting of alfalfa or close early grazing of bluegrass are recommended as antidotes for dry weather. In fact, the authors feel that very early and continuous close grazing of bluegrass (especially when soil fertility is deficient) and early cutting of alfalfa for hay are so hazardous in other respects as to make them generally impractical under the environmental conditions of Wisconsin. The results on water utilization are offered to explain, in part, observed responses in the field rather than to be recommended as the practices which produce them.

RESIDUAL INFLUENCES OF PREVIOUS CUTTING AND NUTRITIONAL TREATMENTS

After June 13 all cultures were permitted to grow without further cutting and fertilization treatments. The top growth was removed completely from each culture on July 18. During these 35 days, the greenhouse temperatures were very high and the high-reserve (+CHO) alfalfa produced a remarkably rapid growth, exceeding or equaling the amount of dry top growth produced during the period of 65 days from April 9 to June 13. On the other hand, the productivity of all cultures of bluegrass was very much less under the high temperatures of June and July than it had been during the previous and cooler period.

Previous clippings (—CHO) reduced the subsequent productivity of the fertilized (+N) alfalfa 52% and of the unfertilized (—N) cultures, 66%. With bluegrass such reductions were 89% (+N) and 47% (—N), respectively.

With high temperatures, the daily rate of water utilization (Fig. 1) of the alfalfa (+CHO) with high reserves, increased with amazing rapidity as did the top growth, varying from 39 grams of water per day in the period about June 15 to 600 grams on July 4 in the case of the +N cultures. The range was quite similar and the rate was only slightly lower for the unfertilized (+CHO) cultures. The daily rate of water utilization of the low-reserve (—CHO +N) alfalfa was much less as was the top growth, ranging from 36 grams to 342 grams of water per day. Previous nitrogen fertilization had a pronounced effect on the growth of the low-reserve (—CHO) alfalfa, increasing the subsequent productivity 86% and increasing the rate of water utilization materially. Nitrogen fixation may well have been decreased by low reserves and high temperatures. Where the reserves were high (+CHO), nitrogen increased subsequent productivity only 31%.

Although previous applications of nitrogen to the high-reserve alfalfa increased subsequent growth 31%, it required only 8.6% more total water to produce this growth. Nitrogen, therefore, reduced the water requirement as it did previous to June 13. Where the reserves of alfalfa were low (—CHO), nitrogen increased the subsequent top growth 86%, but the total water utilized increased only 22.8%. Under all conditions of these trials, nitrogen fertilization reduced the water requirements of alfalfa.

Prior to June 13, the water requirement of alfalfa under a system of weekly defoliations at a 2½-inch level was much lower than with alfalfa not cut until June 13. During recovery, after June 13, the alfalfa was not cut until (July 18) and in this period the water requirement of the low-reserve (—CHO) alfalfa was much greater than the high-reserve (+CHO) alfalfa. It appears that the limitations of nitrogen and food reserves greatly increased the water requirement of the subsequent (June 14 to July 18) growth of the alfalfa.

Probably due to excessive heat in June and July, the low nitrogen (—N) and especially the low-reserve cultures of bluegrass were very unproductive and the water requirement was very high. Nitrogen increased the residual productivity of high-reserve (+CHO) bluegrass 166.5%, but it reduced that of the bluegrass with low reserves 46%. With weekly clippings prior to June 13, at a ½-inch level, the reserves of bluegrass were reduced to a very low level, particularly with the stimulation of nitrogenous fertilization, but all the low-reserve cultures of bluegrass were very unproductive after June 13.

Because of such very meager recovery of bluegrass with low reserves (—CHO) and with high reserves and low nitrogen (+CHO —N), the experimental error resulting from evaporational losses of the unsealed portions of the culture covers was probably too large to warrant full reliance on the determinations of water requirement. This situation was also aggravated by high greenhouse temperatures in June and July. However, giving due allowance for such error, the very high water requirement of the low-reserve cultures of bluegrass during the hot period of July and August would seem to be due to marked limitation of growth resulting from very low reserves. Since, with the previous clipping treatments, nitrogen fertilization had lowered the reserves more than the absence of such treatment, the water requirements of the high-nitrogen low-carbohydrate (+N —CHO) cultures of bluegrass was greater than the low-nitrogen low-carbohydrate (—N —CHO) cultures of bluegrass. Barring this one exception, nitrogen has consistently reduced the water requirement of bluegrass and also of alfalfa.

SUMMARY

A comparison of the water utilization of alfalfa and of Kentucky bluegrass was made under greenhouse control with optimum conditions of moisture and under frequent and deferred cutting treatments, with and without nitrogen fertilization.

The daily rate of water utilization was low in the vegetative stages of growth of alfalfa and bluegrass but increased directly with the rate of top growth accumulation and hence was very high with plants allowed to approach maturity. With weekly clippings which maintained a vegetative state of growth, the daily rate of water utilization was low and quite constant.

Weekly defoliations of well-established, high-reserve cultures of alfalfa greatly reduced the total amount of water utilized and the water requirement during the first 65 days of growth. Such defoliations also reduced the total amount of water utilized by bluegrass, but the water requirements were not greatly affected.

The after effects of the nine weekly defoliations, which lowered the food reserves of alfalfa moderately and the food reserves of the closely clipped bluegrass very severely, were manifested by marked limitations and reductions in subsequent top growth and the total amount of water utilized to produce it, but such previous cutting treatments increased the amount of water needed to produce one unit of dry top growth.

With but one exception, the well-known tendency of nitrogen fertilizations to increase the total water used but to decrease the water required per unit of dry matter produced was clearly evident. It would appear that when growth is definitely limited by reductions in the reserves of bluegrass and alfalfa or by nitrogen deficiencies, the water requirement is increased.

Assuming that the variations in water utilization previously described would apply to comparable treatments of grazing and cutting under field conditions, it is clear that in periods pending drought, early cutting of alfalfa and close early grazing of bluegrass would tend to maintain a greater reserve of moisture in the soil for subsequent growth than would prevail with deferred grazing or cutting. Moisture utilization may, therefore, be a prominent factor in accounting for other than inherent differences in the rate of recovery of the growth of alfalfa with early and deferred cutting and to differences in the rate of recovery of bluegrass with similar contrasts in grazing management. Early cutting and close early grazing are not recommended as antidotes for dry weather but rather to explain, in part, field responses they produce.

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NEW DISEASE-RESISTANT EARLY OATS FROM A VICTORIA-RICHLAND CROSS[1]

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PRIOR to the introduction of Victoria (C. I. 2401)[3] in 1927, no varieties of oats possessing high resistance to crown rust were available to the plant breeder. The best resistance up to this time was found in some of the Australian varieties, such as Ruakura and Sunrise, and in certain strains of the Green Russian oat, such as Rainbow and Schoolmam. The discovery of the high resistance of Victoria to crown rust in 1929 has served greatly to stimulate interest in breeding to eliminate the destructive effects of this disease in the United States. The introduction of Bond (C.I. 2733) in 1929 made available to breeders another variety with high resistance to many physiologic races of crown rust.

Victoria also is highly resistant to all races of the oat smuts tested, which includes most of those so far collected and identified, while Bond apparently has resistance only to certain races. Since their introduction these varieties have been employed extensively in breeding improved varieties with high resistance to crown rust and smut. Results obtained with a cross of Victoria on Richland are reported in this paper.

A considerable portion of the present oat acreage of the Corn Belt is sown to improved early varieties developed cooperatively by the Iowa Agricultural Experiment Station and the U. S. Dept. of Agriculture. The commercial production of these early varieties, namely, Albion (Iowa 103, C. I. 729), Iowar (C. I. 847), Richland (Iowa 105, C. I. 787), and Iogold (C. I. 2329), has contributed materially to the agricultural wealth of the country. Richland and Iogold have been especially outstanding because of high yield and excellent resistance to stem rust, although lacking resistance to crown rust and to smut. Burnett, Stanton, and Warburton (2),[4] Stanton, Griffee, and Ether-

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa Agricultural Experiment Station, cooperating. Journal Paper No. J-574 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 73. Some data were obtained on the smut resistance of these selections in cooperation with the Idaho Agricultural Experiment Station and the Brooklyn Botanic Garden. Yield data were obtained only in 1937 in cooperation with the Ohio, Indiana, Illinois, Missouri, Nebraska, Michigan, Wisconsin, North Dakota, and Oregon Agricultural Experiment Stations. Received for publication, September 27, 1938.

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[3]Accession number of the Division of Cereal Crops and Diseases, formerly Division of Cereal Investigations.

[4]Figures in parenthesis refer to "Literature Cited", p. 1008.

idge (10). Stanton, Love, and Gaines (11), and Burnett (1) have reported on the development, distribution, and value of these varieties.

Murphy and Stanton (7) reported the introduction of Victoria from Uruguay, South America, and the high resistance of this variety to severe epidemics of crown rust at Ames, Iowa, and Manhattan, Kans., in 1929, and its uniform resistance to the eight physiologic races of crown rust collected throughout the United States in the same year. Stanton and Murphy (12) give further details concerning the breeding and development of Victoria in South America. Murphy (4) found that Victoria was resistant to 33 physiologic races of crown rust collected in the United States, Canada, and Mexico in the 6-year period, 1927–32, and that it was highly resistant in field tests conducted in the principal oat-growing regions of the United States during the period 1929 to 1932. In a later report, Murphy (5) showed that Victoria was resistant to 37 races of crown rust collected in the United States, Canada, and Mexico in the 9-year period, 1927–35, and to all collections of smut used in field and greenhouse experiments at Ames, Iowa, during the same period. Murphy and Levine (6) found Victoria susceptible to an apparently new and rare race (No. 41) of crown rust collected in Texas in 1935.

THE VICTORIA-RICHLAND CROSS

Stanton, et al. (13) and Stanton (9) discussed the Victoria×Richland cross (X S1098) and the development of the selections with which this paper is concerned, up to and including the fifth generation. Stanton, et al. (13) also described a second group of selections from the Victoria-Richland cross, tested mainly for disease resistance in the greenhouse at the Arlington Experiment Farm, Arlington, Va., and at Aberdeen, Idaho.

Seed of individual F_5 plants of the Victoria-Richland cross selected from the more promising progenies grown at Ames in 1933 was sown in the greenhouse at Arlington Farm in the fall of 1933. These selections were inoculated with spores of crown and stem rust and with the oat smuts collected in the Corn Belt. A high percentage of them continued to show satisfactory resistance to all these diseases. Seed from the more desirable plants grown in the greenhouse was sown at Ames in the spring of 1934 but failed to germinate owing to the very severe drought that year. Remnant seed from a number of the plants, however, was sown at Aberdeen, Idaho, the same season and among selections from these F_6 progenies were early, small-kerneled types resembling the Richland parent. Certain plants that were especially outstanding for earliness and high tillering capacity have given rise to most of the strains that were advanced to small increase plats at Ames in 1937. These trace back to three F_4 plants which arose from single F_2 and F_3 plants.

No smut infection occurred in any of these progenies inoculated and sown at Aberdeen in 1934. Seed of 48 of the more vigorous F_7 plants were sown in single 15-foot rows at Ames in 1935. These new rust- and smut-resistant strains were unusually promising in yield and were fair to good in grain quality. All of the 48 lines were grown in duplicated 15-foot rows at Ames in 1936 and 12 of the best were grown also in duplicated 4-row (15-foot) plats. Similar plantings of these same selections also were made at Kanawha in northern Iowa. Ten of the highest yielding selections were grown in field plats at Ames in 1937 and others were con-

tinued in nursery tests. Certain selections also were sent to experiment stations in other states for testing. Some of the newer re-selections may prove superior in straw characters and grain quality to the strains being grown in field plats.

METHODS OF INOCULATION

CROWN AND STEM RUST

Urediospore suspensions of physiologic races of crown and stem rusts, common throughout the North Central states, were injected hypodermically into susceptible Markton plants in border and alley rows. The inoculations were made when the plants were 8 to 10 inches high and resulted in their complete infection in the border and alley rows when they reached the boot stage. The rust, disseminated from these infected rows, combined with the natural infection, was sufficient in each year, except 1934, to produce a maximum infection on all susceptible plants in the 5-foot rows of the hybrid nursery.

No attempt was made to initiate epidemics of either crown or stem rust in the rod-row and 1/20-acre plats because of the adverse effect it might have on the yield of the check varieties. Rust infection resulting from natural dissemination, particularly of crown rust in 1935, usually was sufficiently heavy, however, to allow accurate observations of the relative resistance of the selections and their parent varieties.

SMUTS

Tests for resistance to the smuts of oats were made in both field and greenhouse beginning with the F_3 generation of most families. In nearly all years inoculum was used that had been collected from commercial fields in the Corn Belt. Usually spores from plants smutted in the previous generation were added to this inoculum to make sure that the races commonly found in the Corn Belt, as well as any existing unidentified races, might be present. No effort was made to separate the two smut species, although there usually was a preponderance of loose smut (*Ustilago avenae*) in the collections, as a high percentage of the smut occurring in the more humid regions of the United States is of this species.

The hulls or glumes were removed from all seed (caryopses) before inoculation with smut spores. Usually the seeds were dusted with smut spores by placing a small quantity of the inoculum in the seed envelope and then shaking until all seeds were blackened. New smut inoculum was used each year. The temperature in the greenhouse was maintained at about 75°F for 6 or 7 days immediately following seeding to favor the germination of the smut spores.

At harvest all plants showing any smut infection were discarded. Usually smut-free plants lacking vigor, earliness, or desirable grain characters also were discarded.

EXPERIMENTAL DATA

RUST AND SMUT RESISTANCE

In general, the selections were so consistently free from rust and smut under field conditions in 1935 and 1936 that few detailed notes could be recorded. Of the 48 selections grown in 15-foot rows at Ames in 1935, 40 had an infection coefficient of 2 and 8 a coefficient of 3 for crown rust, in contrast with 60 for the susceptible Richland parent variety. All the selections were highly resistant to stem rust, with an infection coefficient of 1 as contrasted with 50 for the Victoria parent.

Selection 550 was very susceptible to halo blight in 1935. There was no marked natural epidemic of either crown or stem rust at Ames or Kanawha in 1936, and as a consequence little or no rust was present even on the susceptible Markton check, except in plantings subjected to artificial inoculation. At both Ames and Kanawha not a single panicle infected with smut was observed in any of the 48 selections grown in replicated nursery rows. However, there was a considerable number of smutted panicles in nearly all check rows of Iogold.

In 1937, 24 of the Victoria × Richland selections were grown in disease nurseries at Ames and Kanawha, Iowa. Sixty hulled (dehulled) kernels of each selection and check variety were dusted with smut spores and space planted in rod rows. The smut used for the test at Ames was obtained from a composite lot of smutted panicles collected from the oat-breeding nursery at Ames in 1936, while, at Kanawha, a collection obtained from a local farmer's field in 1936 was used. Crown rust infection was initiated at Ames by hypodermic inoculation of Markton plants growing in border rows. The stem-rust infection at both locations and the crown rust at Kanawha resulted from natural dissemination. The reaction of the 24 selections and their parent varieties, and of the Iogold check, to smut and both rusts at Ames and Kanawha in 1937 is shown in Table 1.

Except for one plant in selection 508 at Ames, all of the 24 Victoria × Richland selections and the Victoria parent were entirely free from smut infection at Ames and Kanawha in 1937. The Richland parent and a sister selection, Iogold, were approximately 50% infected.

The 24 selections showed some infection with crown rust; however, this infection was of a type that indicated satisfactory resistance and the percentage was low. As a result the average infection coefficient was approximately one-tenth that of the susceptible Richland and Iogold varieties. Field and greenhouse results indicate that these Victoria × Richland selections, and the Victoria parent, have sufficient resistance to all except one of the 46 physiologic races of crown rust known to occur in the United States to afford adequate protection against any ordinary epidemic that might occur. This race, No. 41, apparently is a rare one, collected only in 1935.

The Richland type of resistance to stem rust, which these selections possess, has been sufficient to afford adequate protection from stem rust throughout the Corn Belt during the past 20 years, although two physiologic races of stem rust (Nos. 8 and 10) to which Richland is susceptible, have been known to occur in the United States occasionally during this period. Levine and Smith (3) report, however, that the oat-stem-rust epidemics in the United States during the 15-year period 1921–35 were due almost entirely to the widespread distribution of races Nos. 2 and 5, which constituted 98% of the total isolates identified during that period. Richland and the Victoria-Richland hybrids are extremely resistant to races Nos. 2 and 5 both in the seedling and adult stages.

TABLE 1.—*Reaction to smut, crown rust, and stem rust of 24 Victoria × Richland selections grown at Ames and Kanawha, Iowa, in 1937 in comparison with the Victoria, Richland, and Iogold varieties.*

C. I. No.	Plant sel. No.	Reaction to smut, crown rust, and stem rust*					
		Ames			Kanawha		
		Smut %	Rust, Crown, coeff.	Rust, Stem, coeff.	Smut %	Rust, Crown, coeff.	Rust, Stem, coeff.
2329	(Iogold)	58	75	0	43	30	0
——	501	0	6	0	0	4	0
——	504	0	6	0	0	6	0
3302	506	0	8	0	0	6	0
3303	507	0	8	0	0	6	0
3304	508	3	4	0	0	3	0
3305	509	0	4	0	0	3	0
2329	(Iogold)	45	70	0	54	35	0
3309	517	0	6	0	0	3	0
3310	518	0	6	0	0	3	0
3311	519	0	6	0	0	3	0
3312	520	0	6	0	0	4	0
3313	521	0	6	0	0	3	0
3314	522	0	4	0	0	3	0
3315	526	0	8	0	0	6	0
3316	527	0	6	0	0	6	0
3334	529	0	4	0	0	3	0
2329	(Iogold)	60	75	0	50	40	0
3336	532	0	4	0	0	3	0
3337	543	0	4	0	0	3	0
3338	545	0	4	0	0	3	0
3339	546	0	4	0	0	3	0
3340	550	0	4	0	0	3	0
2329	(Iogold)	64	70	0	47	40	0
2329	(Iogold)	80	65	0	62	30	0
3500	35-419	0	10	0	0	5	0
3501	35-542	0	6	0	0	2	0
3502	35-548	0	8	0	0	4	0
3503	35-609	0	6	0	0	3	0
2329	(Iogold)	72	65	0	63	30	0
787	(Richland)	48	85	0	49	55	0
2401	(Victoria)	0	4	15	0	3	20

*For an explanation of the coefficient of infection of rust, see Murphy (4), page 8.

SMUT RESISTANCE

In the spring of 1937, seed of 16 of the Victoria × Richland selections was sent to Dr. George M. Reed, Brooklyn Botanic Garden, Brooklyn, N. Y., for a re-test of their resistance to the rather large collection of races of the oat smuts available at that institution. Each selection was inoculated with 19 races, including both loose and covered smuts, in accordance with the method devised and used by Reed (8). The results obtained on the reaction of these tester varieties to these races to which the Victoria-Richland selections were completely resistant are presented in Table 2.

TABLE 2.—*Reaction of tester varieties of oats to 19 races of oat smuts to which the Victoria-Richland selections were completely resistant, Brooklyn Botanic Garden, 1937.*

Smut inoculum		Plants infected							
Species and type	Race No.	Hull-less (30)* %	Canadian (119) %	Early Champion (150) %	Gothland (152) %	Monarch (161) %	Kanota (906) %	Red Rustproof (999) %	Fulghum (1000) %
Ustilago avenae—									
Red Rustproof	44	—	35.0	—	—	—	—	17.3	—
	45	—	83.3	—	—	—	—	60.0	—
	47	—	54.5	—	—	—	—	27.2	—
	1	85.0	—	86.9	100.0	0	—	—	—
U. avenae—									
Miscellaneous	26	65.0	—	63.1	0	4.7	—	—	—
	32	100.0	—	68.1	18.1	4.3	—	—	—
	41	66.6	—	95.4	24.0	86.9	—	—	—
	54	61.9	—	71.4	65.2	76.9	—	—	—
	55	85.7	—	100.0	94.1	21.0	—	—	—
U. avenae—									
Fulghum	13	100.0	—	—	—	—	85.0	—	73.6
	18	100.0	—	—	—	—	60.8	—	56.0
U. levis—									
Fulghum	11	—	—	—	—	87.5	—	—	50.0
	12	—	—	—	—	87.5	—	—	45.4
U. levis—									
Miscellaneous	1	85.0	—	87.5	—	100.0	—	—	—
	3	—	—	5.0	—	66.6	—	—	—
	9	83.3	—	76.9	—	81.8	—	—	—
	16	42.8	—	55.5	—	75.0	—	—	—
	19	5.2	—	65.0	—	80.0	—	—	—
	23	47.0	—	76.1	—	91.6	—	—	—

*Special seed numbers for the particular varietal strains used by Reed as host testers in his smut investigations.

The following 16 selections of the Victoria-Richland cross were tested:

C. I. No.	Selection No.	C. I. No.	Selection No.
3301	502	3309	517
3302	506	3310	518
3303	507	3311	519
3304	508	3312	520
3305	509	3313	521
3306	512	3314	522
3307	514	3315	526
3308	516	3317	544

An average of about 20 plants (with a range of from 13 to 25 plants) of each selection and tester variety was grown from seed inoculated

with each of the 19 races of smut. A total of 6,229 plants of the 16 Victoria-Richland selections were grown. One plant of one selection (C. I. 3302), inoculated with race No. 41, was smutted. This plant probably was a rogue. All other Victoria-Richland plants were entirely free from smut, although most of the host tester varieties (Table 2) showed heavy infection when inoculated with the different races of the two smuts. The contrast of their reaction with that of the Victoria-Richland selections is so marked that further comment is unnecessary.

The consistently high resistance of these selections to the oat smuts indicates rather definitely the great value of Victoria as a smut-resistant parent. As Richland is resistant to the races of the oat smuts that attack Fulghum and Red Rustproof, the high resistance of these selections may be due to the bringing together of genes for resistance from both parental varieties. No other group among the numerous hybrid selections tested by the writers in breeding for smut resistance during the past 15 years has been so consistently resistant.

GRAIN YIELD

Limited data on the grain yields of the Victoria-Richland selections were obtained in Iowa at Ames in 1935, 1936, and 1937, and at Kanawha, and also at 10 experiment stations in other states, mostly of the Corn Belt, in 1937. As previously mentioned, 48 selections were first tested for yield at Ames in single 15-foot rows in 1935. These same 48 strains were continued at Ames in 1936, in duplicated 15-foot rows, and a few of the best also were grown in duplicated four-row 15-foot plats. Similar tests of these same selections were made at Kanawha, Iowa, in 1936. In addition, several hundred other selections of the cross were grown in single 15-foot rows at Ames in 1936. A few hundred new panicle selections also were grown in 5-foot rows at Ames for possible isolation of still better lines. Ten of the best selections, as indicated by the results of 1935 and 1936, were grown in 1/20-acre plats at Ames in 1937. However, owing to the fact that in both 1936 and 1937 many of the selections were discarded directly in the field, yield data are available from only a relatively small number. These data from the 20 selections grown three years at Ames and two years at Kanawha are presented in Table 3.

Yields in 1937 at Columbus, Ohio, Lafayette, Ind., Urbana, Ill., Columbia, Mo., Lincoln and North Platte, Nebr., Chatham, Mich., Madison, Wis., Dickinson, N. Dak., and Corvallis, Ore., also are presented in Table 3.

The yield data presented in Table 3 suggest that the Victoria-Richland selections as a group appear to be exceptionally well adapted to the Corn Belt. They have shown marked superiority over the best local standard varieties, particularly at Lafayette, Ind., Urbana, Ill., and Ames, Iowa. They also have shown high yielding ability at Columbia, Mo., and Madison, Wis. The high productiveness of these new selections is indicated by the average yield of the 20 selections grown in 15-foot rows at Ames in 1937. They averaged 96 bushels to the acre as compared with 75.2 bushels for Iogold, a standard early

TABLE 3.—*Annual and average yields of 20 stem-rust-crown-rust and smut resistant selections from the Victoria-Richland cross, and of certain standard varieties as checks grown for one or more years at agricultural experiment stations in the United States, 1935–37.*

C. I. No.	Plant Sel. No.	Acre yield of grain, bushels																					
		Ames, Iowa					Kanawha, Iowa			Average for both Iowa stations	Experiment stations and cooperators in other States—1937 only										Average for all Stations f	Station years	Rank
		1935a	1936b	1937c	Average	Increase plats 1937d	1936e	1937c	Average		Columbus, Ohio, J. B. Park	La-fayette Ind., G. H. Cutler	Urbana, Ill., O. T. Bonnett	Columbia, Mo., B. M. King	Lincoln, Nebr., T. A. Kiesselbach	North Platte, Nebr., Orrin Webster	Chatham, Mich., B. R Churchill	Madison, Wis., H. L. Shands	Dickinson, N.Dak. R. W. Smith	Corvallis, Ore., D. D. Hill		a	
—	501	76.0	71.0	92.6	79.9	—	77.0	67.3	72.2	76.8	—	—	—	—	—	—	—	—	4.8	—	64.8	6	15
—	504	63.0	69.0	91.8	74.6	—	89.0	93.0	91.0	81.2	—	—	—	—	—	—	—	—	9.4	—	69.2	6	12
3302	506	98.0	72.0	109.8	93.3	94.4	90.7	93.0	91.9	92.8	58 0	97.9	49.4	72.6	35.3	28.5	12.9	—	9.6	63.0	63.6	14	16
3303	507	67.0	88.0	99.0	84.7	—	90.0	102 0	96.0	89.2	—	—	—	68.0	—	—	—	—	10.4	—	74.9	7	3
3304	508	99.0	75.4	96.4	90.3	96.2	84.0	103.0	93.5	91.6	46 7	105 4	64 3	76 2	30.6	—	19.5	59.8	—	68.4	71.4	13	8
3305	509	89.0	76.0	96.8	87.3	101.6	85.0	102 3	93.7	89.9	49 0	103.7	60.3	65 7	—	—	20.0	66.4	—	62.6	73.1	12	6
3309	517	93.0	78.2	102.6	91.3	107.8	89.0	97.3	93 2	92 1	—	—	—	59.4	—	—	19.5	64.9	—	66.0	74.4	9	4
3310	518	87.0	87.0	93.4	89.1	101.6	79.0	94.3	86.7	88 1	52 2	91.0	61.6	80.8	41.6	—	20.5	63.3	—	63.2	70.4	13	11
3311	519	101.0	78.6	92.2	90.6	88.4	74.0	94.0	84.0	88.0	54.2	87.4	56.1	76 2	32.3	27.2	15.9	59.5	11.2	61 6	61.4	15	19
3312	520	82.0	75.8	107.4	88.4	103.1	84.7	100.7	92.7	90 1	51.0	96.2	58.5	81.2	34.2	—	24.5	62.7	—	67.8	71.3	13	9
3313	521	86.0	78.8	103.2	89.3	98.1	80.3	101.7	91.0	90.0	48 0	98.9	57.4	65.7	29.6	—	—	60.5	—	—	73.6	11	5
3314	522	92.0	78.6	104.2	91.6	95.0	83.7	94.3	89.0	90.6	50 3	97 0	59.1	81 5	33.6	29.5	14.6	55.2	—	58.4	66.6	14	14
3315	526	113.0	73.8	93.8	93.5	—	75.3	95.0	85.2	90.2	54.7	91.7	55.6	86.1	35.8	—	—	67.9	5.6	—	70.7	12	10
3316	527	67.0	73.0	92.4	77.5	91.2	82.7	85.3	84.0	80.1	51.4	94 2	55.6	—	—	—	—	—	—	—	75.2	8	2
3334	529	60.0	64.0	85.0	69.7	—	92.0	57.3	74.7	71.7	57.5	80.7	47.6	—	32.7	—	—	—	8.6	—	58.5	10	20
3336	532	85.0	64.0	89.8	79.6	—	95.0	88.7	91.9	84.5	44.3	102.2	53.0	—	31.5	26 6	—	—	10.0	—	62.7	11	17
3337	543	87.0	70.0	79.2	78.7	—	98.0	90.0	94.0	84.8	55 8	107.7	50.5	—	31.7	—	—	—	6.8	—	67.7	10	13
3338	545	73.0	67.0	89.4	76.5	—	87.0	81.0	84.0	79 5	57.0	82 5	50.7	—	30.3	—	—	—	6.4	—	62.4	10	18
3339	546	104.0	73.0	106.2	94.4	—	89.0	102.7	95.9	95.0	—	91.2	48 9	—	29.7	—	—	—	—	—	80.6	8	1
3340	550	117.0	58.0	94.4	89.8	—	91.0	60.7	75.9	84.2	—	77.5	46 0	—	30.6	—	—	—	—	—	71.9	8	7
No. of selections		20	20	20	20	10	20	20	20	20	14	16	16	11	14	4	8	9	10	8	—	—	—
Average		87.0	73.6	96.0	—	97.7	85.8	90.2	—	—	52 2	94.1	54.7	73.9	32 8	28.0	18.4	62.2	8.3	63.9	—	—	—
Comparative yieldsg		60.5	78.6	75.2	—	84.4	70.7	76.7	—	—	48.6	92.4	48.6	70 6	32.2	23.8	29.5	53.8	12.3	70 8	—	—	—
Check or standard variety used		Iogold	Iogold	Iogold	—	Richland	Iogold	Iogold	—	—	Franklin	Gopher	Kherson	Columbia	Iogold	Brunker	Iowa 444	State Pride	Gopher	Victory			

a Single 15-foot rows.
b Weighted averages of duplicated 4-row and 2-row plats (15-foot).
c Weighted averages of single 4-row and triplicated 2-row plats (15-foot).
d Single 1/20-acre plats.
e Weighted averages of duplicated and quadruplicated single rows (15-foot).
f Yields from increase plats at Ames in 1937 not included.
g Average of nearest check plats of standard variety.

variety for Iowa. The corresponding yields at Kanawha are 90.2 and 76.7 bushels, respectively. The 10 selections grown in increase plats at Ames in 1937 made the remarkably high average yield of 97.7 bushels as compared with a yield of 84.4 bushels for the Richland check. The one best selection (C. I. 3309) yielded 107.8 bushels an acre, and three other selections of the 10 yielded in excess of 100 bushels. It is believed that the results obtained in this preliminary plat test are indicative of the excellent yielding ability of these new hybrid oats, but further testing is necessary.

The yields of the selections compare favorably with those of standard varieties at some of the other stations. At Columbus, Ohio, the 20 selections grown averaged 3.6 bushels more oats per acre than Franklin. The average for 16 selections at Lafayette, Ind., was 94.1 bushels as compared with 92.4 bushels for Gopher, the check variety. At Urbana, Ill., the average of 16 selections exceeded the Kherson check by 6.1 bushels to the acre. The 11 selections grown at Columbia, Mo., made an average yield of 73.9 bushels as compared with 70.6 for Columbia, a very high-yielding variety now extensively grown in Missouri. At Lincoln, Nebr., the selections on the average only barely exceeded the yield of the Iogold check. Four selections grown at North Platte, Nebr., produced an average yield of 28.0 bushels as compared with 23.8 bushels for Brunker, one of the high-yielding varieties which have been tested for a period of years at that station. Eight selections were tested at Chatham, Mich., but they failed to produce satisfactory yields as compared with Iowa 444, a variety well adapted to that section. It is evident that these selections were somewhat out of their best environment in this northern section. The average acre yield for 10 selections grown at Madison, Wis., is 62.2 bushels, as compared with 53.8 for State Pride, the leading standard early variety for Wisconsin. At Dickinson, N. Dak., the average of 10 selections is 8.3 bushels per acre compared with 12.3 bushels for Gopher. At Corvallis, Ore., these selections as a group were inferior in yield to Victory, a standard midseason variety.

GRAIN QUALITY

Bushel weight or test weight is the standard measure of quality in oats. Weight-per-bushel determinations were obtained on the Victoria × Richland selections in 1936 and 1937 at both Ames and Kanawha. The average bushel weight of all selections grown in the different nursery tests, compared with those of the nearest Iogold checks, are shown in Table 4.

The data of Table 4 show that the Victoria × Richland selections on the average exceeded Iogold by from 2.7 to 4.3 pounds per bushel in the nursery tests in 1936 and 1937 at both stations. The average bushel weights indicate rather conclusively that these selections are decidedly superior in quality to Iogold as well as to most other groups of hybrid selections of early oats under test at Ames.

The 10 Victoria × Richland selections (C. I. 3302, 3304, 3305, 3309 to 3314, inclusive, and 3316) grown in increase plats at Ames in 1937 had an average bushel weight of 32.7 pounds as compared with

TABLE 4.—*Average bushel weight of the Victoria-Richland selections compared with Iogold, grown in nursery plats at Ames and Kanawha, Iowa, in 1936 and 1937.*

Variety	Number of selections	Average bushel weight, lbs.
Ames, 1936		
Victoria X Richland[a]	11	31.8
Iogold (3 checks)	—	27.9
Difference		3.9
Victoria X Richland[b]	20	30.5
Iogold (4 checks)	—	27.8
Difference		2.7
Ames, 1937		
Victoria X Richland	20	28.5
Iogold (4 checks)	—	24.2
Difference		4.3
Kanawha, 1936		
Victoria X Richland[c]	11	26.7
Iogold (3 checks)	—	23.0
Difference		3.7
Victoria X Richland[d]	16	27.2
Iogold (4 checks)	—	24.5
Difference		2.7
Kanawha, 1937		
Victoria X Richland	20	32.6
Iogold (4 checks)	—	29.3
Difference		3.3

[a] 4-row plats.
[b] 2-row plats.
[c] Quadruplicate plats.
[d] Duplicate plats.

28.5 pounds for the Richland checks, a difference of 4.2 pounds. An increase of 3 to 4 pounds to the bushel would add materially to the value of the oat crop in the Corn Belt.

OTHER CHARACTERS

The performance of the Victoria X Richland selections indicates that they are superior to the Iogold and Richland varieties in yield and quality, even where rust and smut were not limiting factors. Apparently, their tolerance to heat and drought, or better adaptation, must be considered. Certain factors on which little tangible information is available, such as resistance to the attacks of soil-borne organisms and minor diseases, may play an important

rôle in the apparent better adaptation of these new hybrid oats. However, further investigation is necessary to evaluate definitely the influence of these factors.

The behavior of the Victoria × Richland selections in the northern latitude of Chatham, Mich., where they failed to grow tall enough and to produce satisfactory yields, may indicate that their range of adaptation is farther south where the climate is warmer.

The data of Table 3 show rather definitely that these selections are evidently well adapted to the central Corn Belt section, where heat and disease are the chief limiting factors in oat production. Limited tests indicate that they also may be adapted to the southern part of the Corn Belt, where strains of Burt and Fulghum are now the leading agricultural varieties.

The performance of the Victoria × Richland selections gives promise of making oats a more productive crop in the Corn Belt. If their high performance is maintained and if now unimportant races of smut and rust, to which these selections are susceptible, do not increase and attack them, one or more of the selections probably will be distributed to farmers in the Corn Belt within the next few years.

SUMMARY

The introduction of Victoria oats from Uruguay by the U. S. Dept. of Agriculture in 1927 made available for breeders a variety with high resistance to crown rust. Later, it was found that Victoria also was highly resistant to the oat smuts.

Victoria has been crossed on many of the best commercial varieties to develop new varieties of oats with high resistance to crown rust and smut. Results with selections obtained from the cross of Victoria on Richland, the latter a high yielding, early oat with high resistance to stem rust and extensively grown in the Corn Belt, are presented here.

Tests in Iowa and other States indicate that, especially under Corn Belt conditions, these selections have a very high yielding ability and high test weight, in addition to their high resistance to the smuts and rusts.

Unless hitherto unimportant races of the smuts and rusts spread and attack these selections, one or more of them probably will be distributed to Corn Belt farmers within the next few years.

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EFFECTS OF VERNALIZATION ON CERTAIN VARIETIES OF OATS[1]

J. W. TAYLOR AND F. A. COFFMAN[2]

IN the southern United States, fall-sown oats are uniformly more successful than are spring-sown oats and winter-killing of suitably adapted varieties is not a common occurrence especially in the Gulf Coastal region. However, winter-killing of oats occurs more frequently as one progresses northward in the United States until finally fall-sown oats usually fail to survive satisfactorily or not at all. Oats of the *Avena byzantina* species, i.e., the red oat varieties, Red Rustproof and Fulghum and their various strains and hybrids, are best adapted in most of the southern half of the United States and they can be grown from both fall and spring seeding.

Numerous field experiments have demonstrated that Fulghum and especially Red Rustproof oats, varieties of *Avena byzantina*, require early spring seeding for satisfactory growth and normal maturity. Stadler (5),[3] in date-of-seeding experiments in Missouri, demonstrated what probably is a difference in the temperature requirements of the Fulghum and Kherson varieties of oats. When seeding was delayed one month, Fulghum suffered a reduction in grain yield of 45%, whereas Kherson, a variety of *A. sativa*, was reduced only 10%. Kherson is classed as a true spring variety, whereas Fulghum may be considered intermediate, i.e., it does not have a complete winter growth habit but requires a period of cool temperatures before normal heading can occur.

The process of satisfying this low temperature requirement either by natural or artificial means is known as vernalization or iarovization, and the economic possibilities of this phenomenon in cereal production have been the subject of some interest and controversy among investigators in recent years. Experiments on artificial vernalization of oats were conducted at the Arlington Experiment Farm, Arlington, Va., from 1933 to 1937, inclusive, and the results are reported herewith.

PREVIOUS WORK

Only a few previous reports on vernalization of oats have been made. Borodin (2) presented results of his vernalization studies of oats in the United States. He obtained definite responses from several winter oat varieties and discussed the practical possibilities of vernalization of oats in America. He was more sanguine of the utility of artificial vernalization than was Martin,[4] who reviewed some of the literature on vernalization and pointed out several limitations to its practical use. Martin stipulated that for vernalization to be practical yields produced from vernalized seed must exceed those resulting from ordinary spring seeding by a sufficient margin to justify the added risk and expense. He further called atten-

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication October 3, 1938.

[2]Agronomists.

[3]Figures in parenthesis refer to "Literature Cited", p. 1019.

[4]MARTIN, J. H. Iarovization in field practice. U. S. D. A., B. P. I., Div. Cereal Crops and Dis., Unnum. Pub., 12 pages. 1934. [Mimeographed.]

tion to the physical problems involved in vernalization on a commercial scale. More recently, a comprehensive review of papers on vernalization the world over has been presented in a bulletin published by the Imperial Bureau of Plant Genetics (3). The reader is referred to this publication for a review of literature.

METHOD OF VERNALIZING OATS

The possibility of using vernalization as a method to increase oat yields from spring seeding to a point approximating the yields of fall-sown oats or surpassing the yields for early spring-sown oats has been investigated at Arlington Farm, Arlington, Va., since 1933.

The steps in the vernalization of the oat seed grown in these experiments were as follows:

1. Approximately 4 pounds of seed of each variety were placed in a cotton bag and soaked in tap water at a temperature of 60° to 65° F for 18 to 24 hours.

2. The excess water was drained off and the bags of oats stored without further attention at a temperature of 32° to 34° F for from 28 to 45 days.

3. The seed was then surface-dried and sown in 15-foot rows replicated two or three times in three-row plats. Untreated lots of each variety were sown adjacent to the vernalized seed. In 1936 and 1937 a second treatment was included. In this the seed was soaked in tap water just prior to seeding but was not subjected to chilling. This latter treatment produced approximately the same results as when dry seed was sown and the data are therefore omitted. Approximately the same number of seeds was sown in all rows of the tests.

4. In 1933, the seed was vernalized 36 days and sown April 10; in 1934, vernalized 42 days and sown April 9; in 1935, vernalized 37 days and sown March 29; in 1936, Iogold, Frazier, and Nortex were vernalized 37 days and all others 45 days and all were sown March 30; in 1937, they were vernalized 28 days and sown April 13.

The three characters studied were (a) heading date, (b) yield, and (c) smut infection. The seed was inoculated with mixtures of spores of loose smut (*Ustilago avenae*) and covered smut (*U. levis*). Several different spore mixtures were used, depending upon the variety, and an attempt was made to inoculate each variety with a smut collection to which it was known to be susceptible. Data are presented in Table 1.

EXPERIMENTAL RESULTS

DATE OF HEADING

The period from seeding to heading, the yield per acre, and the percentage of smutted panicles are given in Table 1. The date of heading of the typically spring varieties was not greatly influenced by vernalization (Table 1). Silvermine and Richland, grown only in 1933, showed no influence at all. Iogold headed in 69 days from untreated seed as compared with 71 days for the vernalized seed for the 4-year period 1934–37. This delay in heading probably resulted from reduced stands in plats from vernalized seed as well as to slower growing and less vigorous seedlings as is shown in Fig. 1, A.

The two Fulghum strains averaged 6 days earlier in heading as a result of vernalization in the 4 years. The greatest difference between treated and untreated seed of C. I. 708 occurred in 1936 when the plants from treated seed headed 12 days earlier than those from un-

TABLE 1.—*Number of days from seeding to heading, yield per acre in bushels, and the percentage of smutted panicles for vernalized and untreated oats during the 5-year period, 1933–1937.*

Variety	Treatment	Period from seeding to heading, days						Yield per acre, bu.					Percentage of smutted panicles			
		1933	1934	1935	1936	1379	Av.	1934	1935	1936	1937	Av.	1935	1936	1937	Av.
						Avena sativa										
Iogold	None	—	64	71	70	72	69	52.0	53.0	60.6	22.4	47.0	2.0	1.9	9.8	4.6
	Vernalized	—	64	73	74	72	71	38.2	35.8	27.2	17.8	29.8	Trace	0	0	0
Richland	None	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Vernalized	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Silvermine	None	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Vernalized	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lee (winter)	None	80	—	80	74	80	79	—	59.2	57.4	2.6	39.7	2.1	6.2	17.0	8.4
	Vernalized	63	—	77	71	74	71	—	55.0	42.8	13.4	37.1	Trace	2.1	1.8	1.3
Winter Turf (winter)	None	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Vernalized	54	—	—	—	—	—	—	—	—	—	—	—	—	—	—
						Avena byzantina										
Fulghum (C. I. 708)*	None	65	—	70	70	73	70	—	59.0	66.4	21.4	48.9	—	1.8	17.1	9.5
	Vernalized	59	—	68	58	71	64	—	62.4	38.0	27.8	42.7	—	0.3	0.4	0.4
Fulghum (winter)	None	—	75	72	70	76	73	51.2	53.8	54.2	2.6	40.5	1.9	7.0	3.3	4.1
	Vernalized	—	61	70	63	72	67	49.8	57.8	50.2	30.4	47.1	0.4	Trace	0.7	0.4
Frazier	None	—	66	69	68	72	69	65.2	47.0	75.4	16.6	51.1	—	1.5	13.9	7.7
	Vernalized	—	56	67	58	69	63	61.6	72.4	56.8	27.0	54.5	—	0	0.4	0.2
Nortex	None	—	70	73	71	76	73	37.0	41.6	66.6	10.6	39.0	—	—	—	—
	Vernalized	—	60	71	63	72	67	48.4	72.8	43.4	25.2	47.5	—	—	—	—
Average†	None	69	70	73	71	75	72	51.1	52.1	64.0	10.8	44.5	2.0	4.1	12.8	6.3
Average†	Vernalized	59	59	71	63	72	65	53.3	64.1	46.2	24.8	47.1	0.2	0.6	0.8	0.5

*C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.
†Not including the true spring varieties Iogold, Richland, and Silvermine.

treated seed. Frazier and Nortex (Fig. 1, B), for the 4-year period, averaged 6 days earlier in heading when grown from vernalized seed. The least difference in date of heading was 2 days and the greatest 10 days.

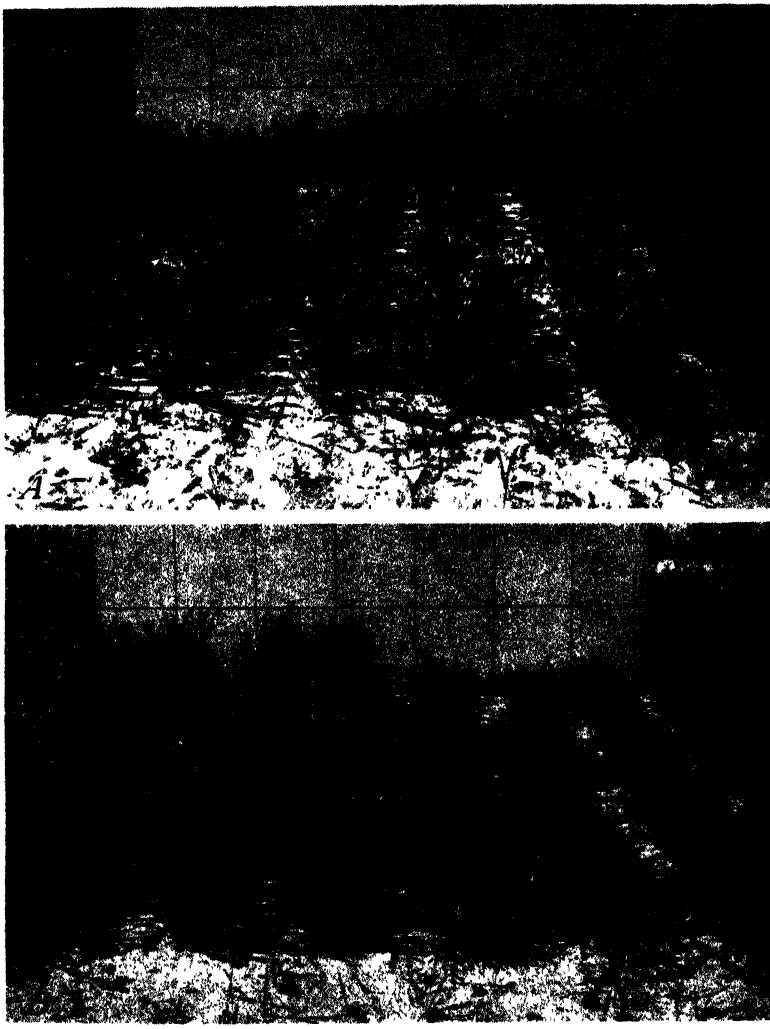

FIG. 1.—*A*, Iogold, a true spring oat variety; vernalized 3 rows at left; check on right. *B*, Nortex, an "intermediate" type variety; vernalized 3 rows at left; check on right.

The time elapsing from seeding to heading for treated seed of Lee averaged 8 days less than for untreated seed. Lee probably requires more time for vernalization than the other varieties.

TABLE 2.—*Species, growth habit, maturity, and vernalization response of oat varieties.*

Variety	C. I. No.	Growth habit	Maturity	Type as determined by vernalization response
		Avena sativa		
Iogold	2329	Spring	Early	Spring
Richland	787	Spring	Early	Spring
Silvermine	659	Spring	Midseason	Spring
Lee	2042	Winter	Late	Winter
Winter Turf	431	Winter	Late	Winter
		Avena byzantina		
Fulghum (winter type sel. 699–2011)	2499	Winter	Midseason	Intermediate
Frazier	2381*	Spring	Early	Intermediate
Fulghum	708*	Spring	Early	Intermediate
Nortex	2382*	Winter	Midseason	Intermediate

*Grown both from spring and fall seeding. Frazier and Fulghum are intermediate in growth habit when fall sown.

In Table 2 the varieties are classified according to their response to vernalization, growth habit, relative maturity, and species for comparison. The classification according to vernalization response is based on the differences in dates of heading of vernalized and unvernalized seed.

INFLUENCE OF VERNALIZATION ON YIELD

The grain yields of Iogold, a spring variety, were reduced by the treatment in all 4 years, averaging 37% less grain than from the untreated check (Table 1). This no doubt was due mainly to poor germination, since the stand in the vernalized rows for the 4 years averaged only 51% of that in the untreated rows. It is probable that vernalization, at least under these conditions, is injurious to the resulting crop unless more important factors exist, such as a low temperature requirement. All varieties averaged at least 20% poorer stand in rows from vernalized seed.

Fulghum (C. I. 708) gave greater yields from the vernalized seed in 2 of the 3 years, but the average for all years was almost 13% less for the vernalized seed.

The vernalized seed of Frazier gave greater yields in 1935 and 1937 and poorer yields in 1934 and 1936 than untreated seed. For the 4 years the increased yield from treatment was but 7%.

Nortex (a strain of Red Rustproof) averaged almost 22% higher in grain yield from the treated seed than from the untreated seed for the 4-year period. Appreciable increases occurred in 1934, 1935, and 1937, while a decrease of 35% occurred in 1936.

Fulghum (C. I. 2499) showed an increase from the treatment in 1935 and 1937, but in 1934 and 1936 there was a slight decrease. For the 4 years there was a gain for the treatment of approximately 16%.

Vernalizing Lee reduced the yield 7%. Decreases were recorded in 2 of the 3 years.

An examination of the data for 1936 and 1937 indicates what may occur as a result of vernalization. In 1936 the seed of certain varieties was treated for 45 days, or 2 weeks longer than was intended, because weather and soil conditions did not permit seeding before March 30. Stands in the vernalized rows were less than 50% that year. Iogold was reduced in yield by 55%, whereas in 1937 the yield of Iogold was reduced only 20% because the treatment was for only 28 days and weather conditions for seeding were more favorable. The seeding date, April 13, was so late that only the vernalized winter varieties made a fair yield.

COMPARISON OF VERNALIZED OATS WITH HIGH-YIELDING SPRING-SOWN AND FALL-SOWN VARIETIES

The yields from the vernalized seed can be compared directly with those of high yielding spring and intermediate type Fulghum oats grown on comparable adjoining land. The spring oat nursery was sown as early as possible. In 1934 and 1936 both the vernalized and spring oat nurseries were sown on the same dates, April 9 and March 30, respectively. The spring oat nursery was sown March 19 or 10 days earlier than the vernalized nursery in 1935, whereas in 1937 the spring oat nursery was sown March 24 or 20 days before the vernalized experiment.

Columbia, a spring oat, averaged 55.4 bushels per acre for the period 1934 to 1937, inclusive. Frazier, grown from vernalized seed, averaged 54.5 bushels for the same years. The yields of Fulghum in the spring oat nursery did not differ materially from those obtained in the vernalized experiment.

The Frazier variety produced the highest average yield from the vernalized seed in the 4-year period. Lee oats, when fall sown, produced over 21% more grain than the vernalized Frazier for the same 4-year period. Even Fulghum (C. I. 708) which was almost entirely winter-killed in 1936 yielded slightly more grain in the 4 years than vernalized Frazier and almost 30% more grain than spring-sown vernalized Fulghum.

EFFECT OF VERNALIZATION ON OCCURRENCE OF SMUT

More smut was observed in the untreated rows of both Lee and Winter Turf in the preliminary vernalization experiment in 1933. The crop of 1934 contained no smut. In 1935, Iogold, Fulghum (C. I. 2499), and Lee again showed much less smut in the crop from treated seed. The seed used in 1936 and 1937 was artifically inoculated with smut before it was vernalized. A sample of the seed of each variety was soaked before sowing to determine the effect of soaking without vernalization on subsequent smut occurrence. An average number of 40.5 smutted panicles per row was found in the soaked seed lots, whereas the dry or untreated seed produced 37.9 smutted panicles per row. This difference is not considered significant. Iogold averaged 4.6% smutted panicles per row (Table 2) as compared with

only 1 smutted panicle in all 3 years in the plants from the vernalized seed. In Fulghum (C. I. 708) there was an average of 9.5% smutted panicles per row from the untreated seed and but 0.4% from that vernalized. Frazier, Fulghum (C. I. 2499), and Lee all showed similar reductions in smut when the seed was vernalized.

Nemlienko (4) found that vernalized or iarovized wheat had only one-third as much stinking smut or bunt (*Tilletia tritici*) as unvernalized wheat.

Bartholomew and Jones (1) found the optimum temperature for infection of oats with *Ustilago avenae* to be 20° C. The minimum temperature for spore germination was 5° C, appreciably above the vernalization temperature (32° to 34° F) used in the present experiments.

The germination and stands of the vernalized oats in the field sowings were reduced as compared to those from the untreated oats. Smut-infected seedlings, if weaker than the normal seedlings, might be eliminated during vernalization or early growth. In 1937, an experiment was conducted in the greenhouse to obtain further information on the effect of the low temperatures on smut occurrence. A lot of Frazier oats was smutted heavily and half of it was soaked for 18 hours in tap water and stored for 3 weeks at 32° to 34° F. The other half was soaked for 18 hours prior to seeding. A seeding of 110 kernels of each of the two lots was made on the same day. More than 100 plants were produced by each lot. The stands were approximately equal, but the untreated seed produced 57.7% smut whereas the vernalized produced 32.1%. Under greenhouse conditions both germination of and smut occurrence in plants from vernalized seed were noticeably higher than under field conditions.

RELATION OF LOW TEMPERATURE REQUIREMENT TO ADAPTATION OF OAT VARIETIES

In Fig. 2 are shown graphically the lines along which seeding of spring oats is begun on the average on February 15, March 15, and April 15 in the eastern and central United States, and the mean temperature isotherms of 40° and 50° F for February, March, and April.

There is a close relationship between the 50° F March isotherm and the northern limit of the zone in which oats of the Red Rustproof type give best results from spring sowing. The Red Rustproof oat usually does not yield satisfactorily when sown north of this line, because it frequently does not reach the heading stage sufficiently early to escape injury from hot weather. Fulghum, on the other hand, matures earlier, permitting it to escape summer heat.

Fulghum oats when spring sown usually do not develop satisfactorily when seeded much north of the area in which spring seeding of oats begins by March 15. In addition, Fulghum oats rarely yield better than oats of the *Avena sativa* type when sown north of the 50° F April isotherm.

In recent years, many farmers in Nebraska and Iowa have followed the practice of seeding Fulghum oats in February or even late in January when weather permitted. Oats sown at these early dates are locally spoken of as winter oats and frequently outyield the varieties

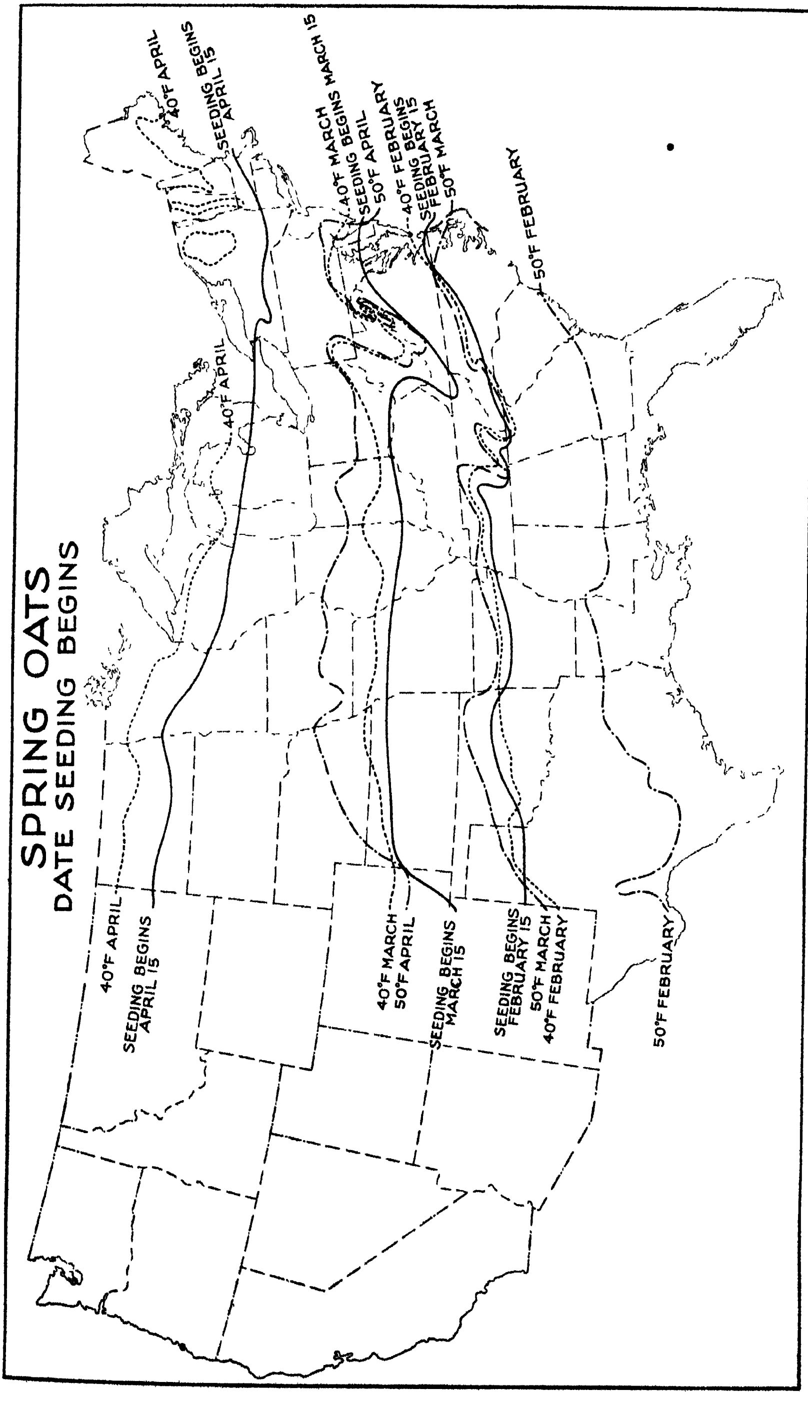

FIG. 2.—Relation of temperature to the time of seeding spring oats in the United States.

sown at the usual seeding date. Doubtless the reason for the favorable yields obtained from such early seedings is that the low temperature requirements of the variety are satisfied which is not the case when sown at the usual seeding date.

This distribution of Red Rustproof and Fulghum, the early seeding dates recommended, and the temperatures at this time seemingly are the result, in part at least, of the low temperature requirements of the varieties. Martin[5] suggested this probable temperature relationship in Fulghum oats in discussing the results presented by Stadler (5). Other than this brief reference, no discussion of the probable low temperature requirement as an explanation for the necessity for early seeding of the red oat has been found. Frazier and Nortex are red oat (*Avena byzantina*) types and both responded to vernalization. Iogold, Silvermine, and Richland varieties of *Avena sativa* showed no low temperature response and these varieties are no doubt less affected by seeding date. This probably explains the big decrease in yield reported by Stadler (5) when he sowed Fulghum a month late as compared with Kherson, a spring variety which has no similar low temperature requirement. Table 3 indicates a probable relationship of cool temperatures following seeding to yield of Fulghum and Kherson oats as reported by Stadler (5) for Columbia, Mo., in 1921, 1923, and 1924. For most favorable results, it is probable that Fulghum and Red Rustproof should be sown during a period when the average

TABLE 3.—*Average mean and minimum temperatures during the 15- and 21-day periods following seeding oats at Columbia, Mo., together with yields obtained.**

Seeding date of oats	Average temperature in °F following seeding				Yield per acre, bu.	
	21 days		15 days		Fulghum	Kherson
	Mean	Minimum	Mean	Minimum		
			1921			
March 17	54.4°	43.7°	51.5°	41.3°	55.3	37.2
March 31	53.9°	43.3°	55.0°	44.9°	42.5	37.0
April 14	54.5°	44.5°	56.5°	46.2°	31.4	30.0
April 28†	57.0°	48.0°	55.9°	47.3°	6.3	13.4
			1923			
March 5	38.4°	27.8°	36.2°	26.8°	42.1	35.7
March 27	45.7°	34.4°	43.9°	31.7°	34.0	29.6
April 12	57.7°	47.1°	55.1°	44.3°	17.8	30.3
			1924			
March 22	48.1°	38.0°	44.8°	35.7°	60.6	48.2
April 5	59.0°	47.1°	58.7°	46.7°	53.7	48.9
April 12	58.9°	47.5°	60.3°	48.7°	38.2	40.5
April 19	58.4°	47.8°	58.0°	46.7°	37.8	42.9
April 26	56.3°	46.0°	57.1°	47.3°	39.2	39.2

*Yields quoted from Stadler (5). Temperature records for Columbia, Mo., are from Climatological Data of the U. S. Dept. of Agriculture Weather Bureau.

†It seems probable that the very low yields obtained from the seedings of April 28, 1921, were at least partly due to heat injury before the plants ripened.

[5]See footnote 4.

minimum temperature is about 40° to 45° F and that they should be in the ground possibly a month at least before the mean temperature exceeds 55° F. These varieties are both spring and fall sown in the United States and they possess a low temperature requirement which must be satisfied for best yields.

SUMMARY

Six oat varieties were vernalized in each of 4 years. Two were winter varieties, three were intermediate in growth habit, and one was a spring variety. Winter and intermediate varieties require a period of cool temperatures for normal growth and development. It is probable that the red oat varieties, Fulghum and Red Rustproof, should be planted in the spring when the average minimum temperature is about 40° to 45° F.

The vernalization of oat seed hastened the heading date 2 to 10 days in the varieties with a low temperature requirement. An average shortening of the period from seeding to heading of 6 days, due to vernalization, was obtained in these varieties during the 4 years. Spring oats showed no hastening of heading, the Iogold variety having been retarded by vernalization in certain years.

Frazier, Nortex, and Fulghum (C. I. 2499), on the average, yielded higher from the vernalized seed than from untreated seed. The greatest increase occurred in Nortex in which the average yield was over 20% higher. Lee and Fulghum (C. I. 708), as well as the spring variety Iogold, showed decreased yields from vernalization. The 4-year average yield from untreated seed of the spring variety, Iogold, was the same as the average of the five winter and intermediate types after vernalization. Spring oats sown early outyielded all of the vernalized oats and fall-sown oats yielded about 20% more grain than the highest yielding vernalized variety.

Vernalization greatly reduced the occurrence of oat smut. Iogold, in the 3 years that smut occurred, had an average of 4.6% smutted panicles per row as compared with but one smutted panicle in the vernalized rows in all 3 years.

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PROBLEMS IN EVALUATING PASTURES IN RELATION TO OTHER CROPS[1]

H. L. AHLGREN, G. BOHSTEDT, AND O. S. AAMODT[2]

STUDIES of pasture improvement through fertilization and management are comparatively new. Since 1920 a considerable body of data relative to the effect of fertilization and management on the yield, chemical composition, and survival of various pasture crops has been assembled in the United States and elsewhere. Valuable as this early work has been, there is an urgent and ever-growing need for additional information which would permit of an accurate evaluation of pasture crops in relation to each other and to other crops grown as feed for livestock. In general, the pasture agronomist is well fortified with facts and figures relative to increases in production of forage which may be obtained from a well-planned fertilization and management program. However, he is often at a loss to know how best to sell his ideas to those who should be vitally concerned because he cannot interpret his results in terms of relative dollars and cents values. This is due primarily to the scarcity of facts and figures for comparing the relative value of various pasture crops and of pasture crops with other harvested feed crops. Consequently, his work has not found as wide a reception among farmers as the present condition of millions of acres of pasture land would appear to warrant.

At present the number of acres of various pasture crops found on an average farm is determined largely by topography, climate, soil type, and type of farming. In general, the acreage devoted to pasture is not based on the value of pasture in relation to other crops grown on the farm. Agronomists have gone ahead on the assumption that a certain amount of land in pasture makes for greater efficiency in land use. It is the purpose of this paper to present the problems associated with, and call attention to, the need for evolving a technic which can be used in evaluating various types of pasture crops in relation to themselves and to other crops which are grown as feed for livestock. It is only through studies of this type that a proper valuation can be placed on crops which are grown for and harvested by livestock.

PRODUCTION RECORDS NEEDED

On a well-managed dairy farm accurate production records are kept for each of the producing animals. In this way it has been possible to remove unprofitable, inefficient, low producers from the herd. It would appear that the same principle could be made use of in evaluating such pasture crops as Kentucky bluegrass, timothy, alfalfa, sweet clover, sudan grass, rye, oats, and others in relation to each

[1]Paper read as part of a symposium on "Comparative Nutritive Value of Crops" at the summer meetings of the A.A.A.S. held at Ottawa, Canada, June, 1938. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication October 5, 1938.

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other and to other harvested feed crops. No doubt there are many situations where crops now used would be replaced were their actual performance values known. At present there are insufficient data with which to compare the nutritive value of various pasture crops with each other and with other feed crops. Such limited data as are available are not in agreement. This would be expected in view of the diversity of soil, topography, climatic conditions, and the species available for grazing which exist in the United States. The limited work that has been done serves to emphasize the need for further extensive investigation in all regions where livestock farming is of major importance.

White (28),[3] working in Pennsylvania, has reported that a 4-year, 4-acre rotation of corn, wheat, oats, and hay produced 8,407 pounds of total digestible nutrients as compared with 8,535 pounds of total digestible nutrients from a 4-acre pasture made up largely of Kentucky bluegrass during the same period. He concludes that "the economic importance of pasture feeding as compared with a system of grain rotation seems to justify the use of land for highly productive pastures similar to that now used for cultivated crops." On the other hand, it is extremely doubtful if the average run of non-rotational pastures are as productive as other crop lands. Generally they have been relegated to the poorest land on the farm. Such fertilizers as have been used have been applied to other crops. In a survey conducted in Wisconsin (15) and covering a 14-year period (1914–1927, inclusive), it was found that the lowest acre production of total digestible nutrients was obtained from permanent pastures. Detailed results of this survey appear in Table 1.

TABLE 1.—*Comparison of the amount of digestible feed nutrients produced per acre by different crops, 14-year average.*

Crop	Total digestible nutrients produced per acre, lbs.
Alfalfa	2,683
Alfalfa (limed)	3,096
Clover	1,838
Timothy	1,552
Corn silage	2,905
Corn	1,939
Barley	1,250
Oats	867
Kentucky bluegrass pasture	846

There is little agreement between the Wisconsin and Pennsylvania figures. There is need for further clarification of the problem with greater consideration directed toward the relative value of various species of crops used for pasture. There is reason to believe that the Wisconsin figures represent the situation more nearly with respect to pastures in general than those obtained in Pennsylvania.

Among the crops listed in Table 1 alfalfa is undoubtedly favored by being grown on the best land on the farm. Likewise, it is generally

[3]Figures in parenthesis refer to "Literature Cited", p. 1028.

true that no attempt has been made to maintain pastures at the same level of fertility as that common for the other harvested feed crops. For this reason the data presented in Table 1 may be somewhat misleading. Under conditions as they now exist any attempt to evaluate permanent pastures in relation to other pasture crops and to crops harvested to be fed to livestock would obviously be unfair. It is to be emphasized that a correct and satisfactory evaluation of pasture crops can be obtained only under conditions where soil fertility conditions are comparable.

COST OF PRODUCTION RECORDS NEEDED

There is very little direct evidence in the literature relative to the cost of producing livestock and livestock products from pasture crops and from harvested crops to be fed to livestock. No attempt has been made to evaluate various types of pasture. It would appear just as desirable to know how much it will cost to produce a crop as to know how much the crop will produce. Obviously the cost of producing various pasture crops as compared to other crops will not be constant for all regions. It will vary from region to region depending upon economic conditions, length of growing period, rainfall, temperature, and soil conditions prevailing in that region. In general it would appear that the more favorable the environment as far as any given species is concerned, the lower the cost of production.

Misner (16) in a detailed study conducted in New York State found that the total cost of pasture and feed used to supplement the pasture was $.097 per cow per day and the cost of winter feed was $.38 per cow per day. The returns from milk during the period the study was made averaged $.34 per cow per day. Figures released by the U. S. Dept. of Agriculture (29) from studies relative to the cost of production of 100 pounds of total digestible nutrients from various crops grown in 16 states are shown in Table 2.

TABLE 2.—*Cost of producing 100 pounds of total digestible nutrients from various crops.*

Crop	Total digestible nutrients produced by crop	Cost of producing 100 lbs. of total digestible nutrients
Oats	932	2.02
Wheat	1,146	1.88
Barley	1,217	1.70
Corn silage	2,320	1.54
Corn grain	1,778	1.38
Timothy hay	1,257	1.21
Clover and timothy hay	1,347	1.15
Soybeans	1,725	1.06
Red clover hay	1,622	0.97
Alfalfa hay	2,522	0.83
Pasture	—	0.64

Lush (14) in cost of production studies in Louisiana found that butterfat could be produced for 13 cents per pound less on pasture than in winter manger feeding.

The comparatively high cost of barn feeding in relation to pasture feeding has been questioned by some. In most studies which have been made to date all costs of production, including an estimated hourly wage for labor, have been assessed against harvested feed crops. In some cases these costs have been included in making comparisons between the economy of barn and pasture feeding. During the period the cattle are on pasture the farmer devotes practically all of his time toward the care of crops to be fed to his livestock in the winter months. During the winter months the livestock producer has no major interest beyond the care of his livestock. Nevertheless, an additional labor charge incurred through handling and feeding the harvested crops is sometimes included in the cost of production figures. It would appear questionable if these labor costs charged against harvested feed crops are entirely justifiable. The services of the farmer for the care and management of his farm are available at all times. From a purely practical point of view he is interested in a balanced labor distribution program. He has found this possible only when a variety of crops are grown and a diversified type of agriculture is practiced. These facts should warrant due consideration in any studies where comparative costs are being determined.

The limited data which are available relative to comparative costs of milk production in barn feeding and from pasture would appear to indicate conclusively that pastures offer the livestock producer his cheapest and most economical source of feed. Whether the results which have been reported will obtain under all conditions and for all types of pasture crops prevalent in the United States is problematical and can be determined only by further experimentation. The need for clarification and the desirability of developing an accurate, standardized basis for comparing relative feed costs is apparent. Undoubtedly, work of this nature would serve to stimulate a more general interest in pasture improvement.

METHODOLOGY USED IN EVALUATING PASTURES

The lack of information on the value of various pasture crops from the standpoint of cost of production, nutritive value, and total production is due in no small part to the lack of a satisfactory technic for arriving at a proper evaluation. There are few published data giving quantitative returns in terms of livestock gains and livestock products from various methods of fertilizing and managing pastures or from various species of pasture crops. To date chemical analysis and "lawn mower clippings" have been used as an indirect method of procedure in most cases for evaluating pasture crops. Results obtained by these procedures may not necessarily be the same as those obtained under grazing conditions.

The results of pasture investigations which have been undertaken in the United States would be of considerably more value if the technic used in the evaluation were more uniform. Schuster (25), in a survey of the literature, has pointed out that there are 13 methods of measurement used in determining the productivity of pastures in the eastern United States. The methods listed include profit, hay

weights, clippings, cattle weights, sheep weights, photographs, surveys, carrying capacity, milk flow, plant population, chemical analysis, palatability, and duration of grasses.

The true carrying capacity of any pasture is determined by the amount of feed produced and utilized rather than grazing days obtained or number of livestock units carried. It would appear to the writers that a measure of the efficiency of any pasture can be determined only in terms of livestock and livestock products which are ultimately produced. Maintenance, production, gain or loss in live weight, and amount of supplementary feed required must all be considered in evaluating various types of pastures in terms of each other or in relation to other crops. Calculations of yield of pasture in terms of total digestible nutrients or net energy and digestible protein appear to be the only available procedures which consider these factors. A similar procedure has been adopted in the Scandinavian countries where the system of feed equivalents has been used with reasonable success in measuring the relative values of various feeds.

In general, the value of various feeds in terms of total digestible nutrients supplied has been determined from feeding experiments. Feeding standards for ruminants which assume the use of both harvested roughages and concentrates have been worked out and are generally available. However, there is little information relative to the nutritive value of those forage crops which are grazed in the more immature growth stages. Facts concerning the relative value of these feeds can be determined only through feeding experiments. Lack of appreciation of the need for data of this type, cost, newness of work, and other difficulties of obtaining quantitative results have limited the investigational work.

The advisability and value of feeding experiments to determine the nutritive value of immature pasture forage crops has been questioned by some workers because it has been argued that the climate of the United States is not generally conducive to a uniform growth of forage throughout the growing period. For this reason it has been thought difficult, if not impossible, to graze in such a manner as to maintain approximately the same amount of forage in comparable growth stages at all times. This lack of uniformity of growth has led some to question the possibility of conducting feeding experiments which would be of any scientific value. During the past few years the agronomist has unconsciously aided in making uniform feeding experiments possible through improved pasture technic. It is now generally recognized that no one crop is capable of providing an abundance of highly nutritious forage throughout the growing period. The single-crop pasture plan has been replaced by a plan which calls for a succession of crops each of which is grazed intensively during its period of most rapid growth. By a scheme of rotation the agronomist has been better able to manage the various pasture crops in such a way as to utilize the forage at such times as it is most palatable and nutritious. Under this system of management it should not be difficult to maintain forage in any stage of growth desired. In the north central and northeastern portions of the United States crops such as sudan grass, rye, oats, alfalfa, and sweet clover have been used to

supplement Kentucky bluegrass. There is need for an accurate evaluation of these crops in relation to each other, to Kentucky bluegrass, and to other crops grown as feed for livestock. Their use makes possible a longer pasture season and eliminates the necessity of grazing Kentucky bluegrass in such a manner as to build up a reserve of surplus forage during favorable growth periods to provide feed of unquestionably inferior quality during unfavorable growth periods.

So far it has been shown that cultivated crops and land devoted to these crops have received major attention and consideration from farmers and research workers alike. The use of cultivated crops has been limited to the best land on the farm which is natural in view of greater initial costs involved and the higher more immediate cash returns which are often obtainable. Barnyard manure and commercial fertilizers when used are usually applied to cultivated crop land. Likewise, improved soil practices, tillage operations, and weed control activities have generally been confined to soil other than that on which pasture crops are grown.

Where evaluation studies relative to various pasture crops and harvested feed crops are to be made, the studies must be conducted under conditions where improved pastures and pasture systems as well as improved cultivated crops and proper rotations are being compared. There can be no other justifiable basis for an accurate evaluation. Such evaluations would aid materially in demonstrating that a planned pasture improvement program based on scientific facts is practical, feasible, and economical. It would also be in accordance with soil conservation and erosion control practices where pasture improvement has been accepted as fundamental.

PRESENT FEEDING STANDARDS NOT ENTIRELY SATISFACTORY

It is to be emphasized that no method of measuring the nutritive value of feeding stuffs yet devised is entirely satisfactory. In the United States the "total digestible nutrients" method has been most widely used in comparing one feed with another. This procedure is satisfactory only when feeds being fed for productive purposes have approximately the same fiber content. In view of this fact various attempts have been made to place various feeds on a common basis with respect to their productive values.

Kellner (12) in Germany developed his "starch values", Armsby (1) and Fraps (6) in the United States, the net energy and productive values, respectively. By using net energy values it is possible to compare concentrates of low fiber content with roughages of high fiber content. However, few relative data are available regarding net energy values of feeding stuffs. Furthermore, no system of feed evaluation yet devised adequately considers palatability and quality of proteins, minerals, and vitamins.

Crampton (3) in work with reed canary grass has shown that proteins present in this forage may be of inferior quality. Orr (23) in a comprehensive review of the world literature has demonstrated the necessity of balanced mineral intakes in the health and well being of livestock. Steenbock, et al. (27) and Russell (24) found that clover

hay which had been exposed to sunlight and rain was less valuable as a source of vitamin A than hay cured quickly and still retaining a good green color. Douglas, Tobiska and Vail (4) found that alfalfa hay, cut early, contained more vitamin A and G than hay cut at later growth stages. Hunt and Krauss (11) in a study with various pasture grasses have shown that vitamins A and G decreased as plants approached maturity. Barnes and Hume (2) have shown that milk from cows on pasture contained more vitamin C than milk from cows on winter feed. In 1923, Golding (8) reported that milk from winter feeding might contain as little as one-tenth the vitamin A of milk from cows fed on pasture. Hunt, Record, and Bethke (10) have shown that the vitamin B and G content of alfalfa, clover, and timothy decreased as the plant approached maturity.

Certainly any method or methods of feed evaluation, however accurate otherwise, which does not consider the facts discussed above, is faulty. For the present at least it seems highly desirable to determine as quickly as possible by the technics available the *relative values* of various pasture crops in relation to each other and to other harvested feed crops.

INDIRECT METHOD OF DETERMINING RELATIVE VALUES OF PASTURE FEEDS

From feeding standards and through many years of experimentation there is available a fairly accurate body of data relative to the total digestible nutrient requirements for maintenance and milk production of dairy cows. By computing the requirements for maintenance, milk production, and gain in live weight and by deducting nutrients obtained from supplementary feeds, the amount of nutrients supplied by various pasture crops can be calculated. If accurate yields of forage produced are taken, the digestibility of the forage can be calculated with reasonable accuracy.

On the basis of feeding standards prepared by Haecker (9), Morrison (18), and Forbes, et al. (5), Knott, Hodgson, and Ellington (13) have determined the total digestible nutrients supplied by a number of Washington pastures. On the basis of their evaluations they found that an acre of pasture on which rotational grazing was practiced produced an average of 5,986 pounds of total digestible nutrients annually during the period 1931–33, inclusive. A continuously grazed pasture produced an average of 5,499 pounds of total digestible nutrients annually during the same period, whereas reed canary grass produced 5,254 pounds of digestible nutrients annually. The average acre yield of digestible nutrients from wheat pasture was 1,875 pounds. A similar procedure has been used by Sprague (26) in evaluating pastures of New Jersey. This system is also being used at Wisconsin in an attempt to evaluate various fertilization and management procedures in terms of digestible nutrients supplied from pastures.

Standards similar to those used in computing the nutrient requirements of milk-producing dairy cattle are also available for growing dairy cattle, beef, cattle, horses, and sheep. The method may be open

to criticism because it is indirect; however, it would appear to be reasonably accurate for determining *relative values* of various pasture forages. It should prove highly useful and valuable until such a time as more exhaustive studies have been made on such questions as digestion coefficients and net energy or productive values of the pasture forages; also on maintenance requirement of livestock on pasture. Obviously, pasture research can be broken down into a great many separate steps, or simple variant comparisons, each of which is a problem in itself.

DIRECT METHOD OF DETERMINING RELATIVE VALUES OF PASTURE FEEDS

An exact knowledge of the feeding value of various pasture forages would be extremely valuable. Unfortunately there is very little information in the literature relative to the feeding value of crops grazed at immature growth stages. Newlander (19) determined the coefficient of digestion of oat hay, sudan grass, and millet, all of which were harvested and fed at immature growth stages. Each of the materials was fed as the sole ration since chemical analyses showed them to be fairly well balanced in nutrients. The digestion coefficients of the dry matter of oat hay, sudan grass, and millet were found to be 70.57, 65.25 and 67.96, respectively. In another feeding experiment with sudan grass, Newlander (20) found this forage to contain 58.86% total digestible nutrients on the basis of 86.4% dry matter. Mineral balances obtained in this trial showed losses of calcium and a gain of phosphorus, indicating that dried young sudan grass fed as the sole feed to dairy cows may be deficient in calcium. In further work Newlander and Jones (22) found dried young grass, mostly Kentucky bluegrass, fed as the sole ration to dairy cows to contain 64.37% total digestible nutrients on the basis of 90.17% dry matter. Newlander (21) also substituted artificially dried young grass for hay in a ration and secured increased milk yields. Garrigus and Rusk (7) found young reed canary grass to contain 61.39% total digestible nutrients, whereas brome grass which was practically mature contained 51.79% total digestible nutrients.

As far as the United States is concerned, data relative to the digestibility of various pasture crops is admittedly fragmentary. For the present at least, pasture crop evaluation on this basis is not possible.

According to the best information available, reliable feed values can be determined with any class of livestock by means of feeding experiments which can be conducted at relatively low costs. To be reliable, Morrison (17) suggests that such feeding experiments conform to certain essential facts, as follows:

1. There must be available as a standard for comparison a suitable common feed, the feeding value, or more specifically, the net energy value of which has been definitely established. Dent corn grain would appear to be the best standard for the United States as a whole.

2. The experiment must be arranged in such a way as to determine definitely the amount of feed to be tested which is required to produce the same amount of product as is produced by a definite amount of corn grain of standard composition.
3. All feeds should be carefully analyzed so that a record of the exact composition can be obtained.
4. The check lot which receives corn and the lot which receives the experimental feed must both consume the same amount of all other feeds.
5. The production of the two lots should be equalized as much as possible by increasing or decreasing the amount of experimental feed.
6. The check lot must be fed a sufficient amount of corn and the other feeds that are needed to provide a good and complete ration so that the animals will produce at a satisfactory rate.
7. The animals in both lots must be weighed at periods no longer than 2 weeks. After each weighing the amount of experimental feed must be increased or decreased, if necessary, to equalize the production or gains in weight of the animals in the two lots.
8. At the conclusion of an experiment conducted according to this procedure it will have been determined just how much of the experimental feed has been required to replace each 100 pounds of corn grain that has been consumed by the check lot. From this fact the nutritive value of the experimental feed can be computed.

Perhaps an experimental procedure such as the above can be adapted for comparing pastures among themselves, or for comparing pastures with harvested feeds, primarily roughages. While the harvested feeds could be of a definite quality from the beginning to the end of such an experiment, the pasture might for obvious reasons need to be a rotation or succession of forage crops.

CONCLUSION

It has not been the purpose of this paper to arrive at any definite conclusions relative to the evaluation of various pasture crops. Rather it has been the object to point out the problems involved in such a procedure and the need for, and desirability of, developing a satisfactory standardized technic for evaluating various types of pasture crops. It is evident from a survey of the literature and our own observations, that the type of data needed is not sufficiently complete for general application in the United States. It is the opinion of the authors that a proper evaluation of the producing ability, relative cost, and feeding value of various pasture crops will serve directly in making for a greater efficiency in the use of pasture crops and increased interest in pasture improvement generally.

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REGISTRATION OF VARIETIES AND STRAINS OF OATS, VIII[1]

T. R. Stanton[2]

The seventh report on the registration of improved oat varieties was published in December 1935 (4).[3] No varieties were registered in 1936 and 1937. The varieties submitted and approved for registration in 1938 are as follows:

Group and Varietal Name	Reg. No.
Early Red:	
Fulton	84
Early yellow:	
Carleton	85
Midseason white:	
Bannock	86

Information on the origin, description, performance, and potential value of these new varieties on which approval for registration is based is summarized in the following paragraphs.

FULTON, REG. NO. 84

Fulton (Kans. No. 6138, C. I. 3327)[4] was originated from a cross between Fulghum and Markton oats made at the Aberdeen Substation, Aberdeen, Idaho, in 1926 by G. A. Wiebe, with the idea of introducing the smut resistance of Markton into the Fulghum type. The F_1 plants were grown in the greenhouse at the Arlington Experiment Farm, Arlington, Va., in the winter of 1926–27. An F_2 plant population was grown at Aberdeen in 1927 from which panicle selections were made by F. A. Coffman. Fifty of these selections were grown in 1928 by John H. Parker in the oat breeding nursery maintained cooperatively at Manhattan, Kans., by the Kansas Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

The most promising smut-resistant lines were selected through the F_3 to F_5 generations. In 1931 a selected progeny descended from the F_3 panicle row 39 was given selection No. 303635 and sown in triplicated rod rows. After nursery yield tests from 1931 to 1933, seed of this strain was turned over to H. H. Laude, of the Agronomy Department, Agricultural Experiment Station, Manhattan, Kans., for testing in plat experiments in 1934, at which time Kansas accession No. 6138 was assigned to it.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 29, 1938.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1938 Committee on Varietal Standardization and Registration, charged with the registration of oat varieties.

[3]Reference by number is to "Literature Cited", p. 1036.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

Information on pathologic and agronomic characters forwarded by Dr. Parker, with the application for the registration of Fulton, is summarized in the following paragraph:

For 1931 to 1938, an average of 0.5 and 25.0% of the panicles in Fulton and Kanota, respectively, were infected when the seed was dusted with a composite of Kansas smuts. Fulton has a spreading panicle and a light red kernel that resembles white oats more than Kanota, but it ordinarily will be graded as red oats. Fulton grows from 2 to 3 inches taller, heads from 4 to 6 days earlier, and sometimes ripens from 1 to 3 days earlier than Kanota. The test weight of Fulton is equal or slightly superior to that of Kanota, and like both parents, it is very susceptible to crown and stem rusts. Fulton has a relatively weak straw. Fulton, if planted early, is subject to damage by late spring frosts; however, if planting is delayed, Fulton will usually outyield Kanota.

Briefly then, the superior characters of Fulton are resistance to smut, earliness, high yield, and quality. It will be distributed to farmers of Kansas in the spring of 1939.

Fulton has been tested for yield in nursery rows and field plats at Manhattan, in field plats in regional experimental fields, and in cooperative varietal tests on farms in Kansas. In addition, Fulton has been grown at experiment stations in different States in coordinated yield-test nurseries maintained cooperatively by these states and by the U. S. Dept. of Agriculture. Yield data from these various tests are presented in Tables 1, 2, and 3.

TABLE 1.—*Yield of Fulton and Kanota oats grown in various experiments in Kansas.*

Variety	Acre yield, bushels								
	1931	1932	1933	1934	1935	1936	1937	1938	Av.
Replicated Rod Rows, Manhattan (J. H. Parker)									
Fulton......	77.2*	88.9	45.9	21.6	60.3	54.1	60.5	47.0	56.9
Kanota......	62.5*	72.3	33.8	12.1	60.5	52.7	60.3	51.7	50.7
Three Distributed 1/40th-acre Plats, Manhattan (H. H. Laude)									
Fulton......	—	—	—	23.4†	79.7	51.9	51.4	48.8	51.0
Kanota......	—	—	—	21.1†	79.5	58.0	49.5	53.9	52.4
Cooperative Experimental Tests on Farms (A. L. Clapp)‡									
Fulton......	—	—	—	—	—	—	37.7	38.5	38.1§
Kanota......	—	—	—	—	—	—	36.0	38.3	37.2§

*Three distributed single rod rows in 1931; other years, five distributed plats of three rod rows each.
†One plat only.
‡Five tests each year.
§Average of ten tests.

CARLETON, REG. NO. 85

Carleton (C. I. 2378) was originated from a cross between Sixty-Day and Markton oats made at the Arlington Farm by T. R. Stanton in 1919, at which time the second parent was an unnamed selection (6). The cross was made at the suggestion of D. E. Stephens to

TABLE 2.—*Yield of Fulton and Kanota oats grown in plats on regional experimental fields in Kansas, 1936–38.*

Variety	Region	Location of field	Seeding	Acre yield, bushels 1936	1937	1938	Averages			
Fulton	S. E. Kansas	Moran	Early	51.8	57.7	43.2*	50.9	49.2	51.9	56.4
			Late	—	56.3	37.2	46.8			
		Columbus		—	83.6	—	—	83.6		
		Thayer	Early	—	—	53.5	53.5	42.7		
			Late	—	—	31.8	31.8			
	N. E. Kansas	McLouth	Early	56.7	68.0	68.7	64.5	63.6	63.6	
			Late	65.4	59.0	—	62.2			
Kanota	S. E. Kansas	Moran	Early	51.3	52.7	51.3	51.8	45.8	44.8	53.7
			Late	—	47.7	26.1	36.9			
		Columbus		—	70.0	—	—	70.0		
		Thayer	Early	—	—	52.2	52.2	29.7		
			Late	—	—	7.1	7.1			
	N. E. Kansas	McLouth	Early	64.8	70.6	59.3	64.9	68.0	68.0	
			Late	65.5	79.9	—	72.7			

*Injured by early freeze.

develop an oat that would ripen between Sixty-Day and Swedish Select.

In 1921, seed from the F_1 plants grown at Arlington Farm was sown by D. E. Stephens at Moro, Oreg., where it was grown and selected in the F_2 to F_5 generations. In 1925, B. B. Bayles, then at the Sherman Branch Experiment Station at Moro, smutted the seed from 204 selections. Seventy of the F_6 lines were free from smut and 93 showed an infection of 95% or more. The 70 smut-free selections were again free from smut in 1926. In 1927, 33 of these lines were distributed to other stations for testing. Selection 1045 a3–1–4–1 (C. I. 2378) was outstanding in appearance and in yield at Ames, Iowa, in 1927, and continued to be productive at Ames and at stations in other states. This strain was named Carleton in 1931 in honor of the late Mark Alfred Carleton.

Carleton is an early, yellow, common oat, similar to Kherson or the parent strain Sixty-Day. It differs from most strains of Kherson in having more and stronger awns, a little larger panicle, and slightly longer lemmas. The culms usually are very hairy at the nodes like the Markton parent. Results of repeated tests at many stations have shown that Carleton is highly resistant to nearly all races of the oat smuts. Its superior characters are resistance to smut and *Fusarium*

TABLE 3.—*Yield of Fulton and Kanota oats grown at 10 experiment stations in the United States, 1936* and 1937.†*

Variety	Location of station and average acre yield, bushels										Average of 10 stations	Percentage of Kanota
	Arlington, Va.	Columbus, Ohio	Urbana, Ill.‡	Columbia, Mo.	Lincoln, Nebr.	Manhattan, Kans.	Denton, Tex.‡	Hays, Kans.	Akron, Colo.	Woodward, Okla.		
Fulton	64.1	61.3	46.9	49.2	37.2	57.4	34.4	30.6	41.2	21.7	44.4	123
Kanota	58.2	41.1	44.1	37.3§	26.3§	58.5§	30.0	22.4	28.1	15.6§	36.2	100

*COFFMAN, F. A. Results from the cooperative, coordinated oat breeding nurseries for 1936 and the uniform winter hardiness nurseries for 1936–37, together with average for previous years. U. S. Dept. Agr. Bur. Plant Ind., Div. Cereal Crops and Diseases [Unnumb. Pub.], 128 pp. July 15, 1937. [Mimeographed.]

†COFFMAN, F. A. Results from the cooperative, coordinated oat breeding nurseries for 1937 and the uniform winter-hardiness nurseries for 1937–38, together with average for previous years. U. S. Dept. Agr. Bur. Plant Indus. Div. Cereal Crops and Diseases [Unnumb. Pub.] 108 pp. May 28, 1938. [Mimeographed.]

‡Yield for 1936 only. §Average of several rows.

TABLE 4.—*Yield of Carleton and Markton oats grown in nursery rows and field plats at experiment stations in Oregon.**

Variety	C. I. No.	Acre yield, bushels												
		1926	1927	1928	1930	1931	1932	1933	1934	1935	1936	1937	1938	Average
Sherman Branch Experiment Station, Moro. (D. E. Stephens)														
Nursery plats:														
Carleton	2378	44.4	53.1	59.5	27.0	29.9	14.2	54.0	—	31.0	48.2	41.4	41.6	40.4
Markton	2053	37.2	35.1	56.2	24.8	27.3	9 7	36.6	—	25.4	43.5	37.3	35.0	33.5
Field plats:														
Carleton	2378	—	—	—	—	—	—	—	—	39.6	51.9	59.7	39.2	47.6
Markton	2053	—	—	—	—	—	—	—	—	33.8	51.9	53.7	36.9	44.1
Pendleton Branch Experiment Station, Pendleton (J. Foster Martin)														
Nursery plats:														
Carleton	2378	—	—	—	—	62.4	59.8	87.4	41.6	76.6	81.8	85.6	66.8	70.3
Markton	2053	—	—	—	—	60.3	56.5	81.8	28.4	58.9	85.8	71.8	67.1	63.8
Field plats:														
Carleton	2378	—	—	—	—	—	—	—	—	—	67.6	83.8	77.0	76.1
Markton	2053	—	—	—	—	—	—	—	—	—	77.0	78.3	77.5	77.6

*No yields were obtained at Moro in 1929 and 1934 because of severe drought. Data obtained cooperatively by the Oregon Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

culmorum, high yield, early maturity, and adaptation to dry-land conditions. It has no resistance to the rusts of oats.

Stanton (5) has listed Carleton as a superior strain. Several hundred bushels of seed of Carleton were distributed to farmers in 1937 and 1938 from the Sherman Branch Experiment Station, Moro, Oreg., from which station D. E. Stephens applied for its registration. Numerous nursery yield data on Carleton from many tests have been compiled by F. A. Coffman in annual mimeographed reports.[5] The annual and average yields of Carleton and other standard varieties for comparison obtained at the Sherman Branch Experiment Station, Moro, Oreg., the Pendleton Branch Station, Pendleton, Oreg., and other agricultural experiment stations in dry-farming areas, are presented in Tables 4 and 5.

TABLE 5.—*Yield of Carleton and certain standard oat varieties grown in replicated field plats at the dry-land experiment stations indicated.**

Variety	C. I. No.	Yield per acre, bushels							
		1932	1933	1934	1935	1936	1937	1938	Av.
U. S. Field Station, Sheridan, Wyo. (R. S. Towle)									
Carleton	2378	66.4	46.4	47.5	27.5	8.6	38.4	83.1	45.4
Markton	2053	69.3	49.3	51.6	16.0	8.0	23.5	85.3	43.3
Gopher	2027	70.5	38.9	46.4	25.2	4.0	33.2	80.8	42.7
Iogold	2329	67.0	36.7	47.5	28.1	4.6	34.9	83.1	43.1
Victory	560	45.2	40.1	37.8	13.2	1.7	20.1	76.8	33.6
Dickinson Substation, Dickinson, N. Dak. (R. W. Smith)									
Carleton	2378	30.3	15.6	9.1	36.8	0.3	9.1	16.9	16.9
Markton	2053	37.4	18.2	9.3	35.3	0.2	8.9	12.1	17.3
Gopher	2027	37.7	13.7	8.6	39.2	0.5	7.0	18.1	17.8
Victory	560	32.6	12.1	7.1	25.5	0.4	3.2	4.1	12.1
Northern Montana Branch Station, Havre, Mont. (M. A. Bell)									
Carleton	2378	—	—	—	35.4	3.7	7.8	63.5	27.6
Gopher	2027	—	—	—	34.4	2.4	6.3	61.5	26.2
Markton	2053	—	—	—	33.3	2.8	7.8	53.6	24.4
Idamine	1834	—	—	—	28.6	2.3	4.7	55.7	22.8
Swedish Select	134	—	—	—	30.2	0.7	3.7	49.5	21.0

*Data obtained cooperatively by the Divisions of Dry-Land Agriculture and Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Wyoming, North Dakota, and Montana Agricultural Experiment Stations.

BANNOCK, REG. NO. 86

Bannock (C. I. 2592) originated from a cross between Markton and Victory oats made in 1923 by G. A. Wiebe at the Aberdeen Substation, Aberdeen, Idaho. The F_1 hybrid was grown in the greenhouse at Arlington Farm in the winter of 1923–24. Beginning in 1924 successive generations of selections were grown at the Aberdeen Substation from smut-inoculated seed until 1928, when a group of the resistant selections was tested for yield in 15-foot nursery rows. One of these selections, row No. 4831, in 1928 (C. I. 2592), was named Bannock in 1938 after its smut resistance and high yielding ability had been

[5]Coffman, F. A. See footnote 2, Table 3.

proved in further tests at the Aberdeen Substation and experiment stations in other states. Bannock, therefore, is a product of the coordinated oat-breeding program carried on cooperatively by the Idaho Agricultural Experiment Station and experiment stations in other states and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Those besides the writer who had a part in the breeding of Bannock, are F. A. Coffman, Harland Stevens, John L. Toevs, G. A. Wiebe, L. L. Davis, A. E. McClymonds, and V. F. Tapke. Agronomists of the various experiment stations who tested Bannock and many sister selections are entitled to credit. Bannock was first introduced to farmers of southern Idaho in the spring of 1938, nearly 40,000 pounds of seed having been distributed from the Aberdeen Substation. Application for the registration of Bannock was made by Harland Stevens and John L. Toevs.

Bannock is a midseason white oat with resistance to most physiologic races of the oat smuts. This resistance should continue unless hitherto unknown new races of smut should spread and infect Bannock.

Bannock ripens at about the same time as the Victory parent, is somewhat shorter, and is about equal to it in quality. The straw of Bannock is fairly stiff and the grains have relatively few awns. The superior characters of Bannock are resistance to smut, high yield, white kernels, and high quality. Bannock has been tested in replicated plats at Aberdeen since 1933. The annual and average yields obtained are given in Table 6.

TABLE 6.—*Annual and average yield of Bannock and four standard oat varieties grown in replicated plats at Aberdeen, Idaho, 1933–38.*

Variety	C. I. No.	Acre yield, bushels						
		1933	1934	1935	1936	1937	1938	Av.
Bannock....	2592	138.8	118.8	140.9	118.3	112.9	154.0	130.6
Markton....	2053	142.5	110.9	135.9	122.5	109.5	143.5	127.4
Victory.....	2020	136.7	111.5	137.4	142.5	115.3	139.6	130.5
Idamine .. .	1834	137.5	112.0	133.9	132.1	108.4	134.4	126.4
Abundance.	2038	137.1	115.4	135.2	140.0	121.4	136.7	131.0

TABLE 7.—*Average acre yield in bushels of Bannock and four standard oat varieties grown under irrigation in uniform nursery experiments for 2 to 9 years at the agricultural experiment stations indicated.*

Variety	C. I. No.	Aberdeen, Idaho (1929–37), 9 years	Bozeman, Mont. (1930–37), 8 years	Ft. Collins, Colo. (1930–37), 8 years	Logan, Utah (1932–37), 6 years
Bannock.......	2592	136.3	130.7†	91.5	122.7
Markton.......	2053	124.4	117.3	87.4‡	113.7‖
Victory........	——	123.2*	121.7	85.6§	109.9¶
Idamine.......	1834	125.1	110.1‡	——	104.1¶

*Six-year average.
†Yield of sel. 2592-1, two-year average.
‡Four-year average.
§Nine-year average of Colorado No. 37 substituted.
‖Eight-year average.
¶Seven-year average.

Bannock also has been tested in cooperative, coordinated uniform oat nurseries at other irrigated experiment stations in certain western states. Average acre yields of Bannock, Markton, and Victory, the two parent varieties, and Idamine obtained at the Aberdeen Substation, Aberdeen, Idaho, and the state agricultural experiment stations at Bozeman, Mont., Fort Collins, Colo., and Logan, Utah, as compiled by Coffman[6] are given in Table 7. Credit is due W. B. Nelson, D. W. Robertson, and R. W. Woodward of the state experiment stations at Bozeman, Mont., Fort Collins, Colo., and Logan, Utah, for their part in obtaining the original data on which these averages are based.

Further information on Bannock may be found in the literature on oats (1, 2, 3, 5).

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[6]Coffman, F. A. See footnote 1, Table 3.

REGISTRATION OF IMPROVED WHEAT VARIETIES, XII[1]

J. ALLEN CLARK[2]

ELEVEN previous reports present the registration of 55 improved varieties of wheat. In 1937, two varieties were registered, and as in former years, the previous registration was referred to:[3]

Three varieties have been approved for registration in 1938, as follows:

Varietal Name	Reg. No.
Nebred	321
Pilot	322
Thorne	323

NEBRED, REG. NO. 321

Nebred (Nebraska No. 1063, C. I.[4] 10094) was developed in cooperative experiments of the Nebraska Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The original selection was made in 1924 by T. A. Kiesselbach and Arthur Anderson from a plat of Turkey (S. Dak. 144, C. I. 3684) at Lincoln. The seed for the plat had been inoculated with *Tilletia levis*, and an epidemic of stem rust was created in the spring. Heads were selected from plants free of bunt and relatively free of rust. In succeeding years these selections were inoculated with bunt and only the resistant ones were continued. The testing work became cooperative in 1930, C. A. Suneson and K. S. Quisenberry successively representing the U. S. Dept. of Agriculture. Dr. T. A. Kiesselbach applied for registration.

Nebred is a winter wheat of the Turkey type. The spike is awned with glabrous glumes and has hard red kernels. It is rather winter hardy and midseason as to maturity.

In Table 1 yield data are presented comparing Nebred, Cheyenne, and Turkey at Lincoln. It will be seen that Nebred has outyielded Turkey but is not quite equal to Cheyenne. In the cooperative regional hard red winter wheat improvement program Nebred has been tested in the central district or stations in Kansas, Nebraska, and Colorado. In these tests it has been one of the highest yielding varieties at all stations.

Nebred was selected chiefly for resistance to bunt. In Table 2 data are presented which show that the variety is more resistant to forms of smut in the Great Plains than either Oro or Minturki, two com-

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 29, 1938.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Member of the 1938 Committee on Varietal Standardization and Registration, charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, XI. Jour. Amer. Soc. Agron., 29:1031–1032. 1937.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

TABLE 1.—*Comparative yields of Nebred and other standard winter wheats grown in plat tests (five replications) at Lincoln, Nebr., 1930–38.*

Variety	Yield in bushels per acre									
	1930	1931	1932	1933	1934	1935	1936	1937	1938	Av.
Nebred (new)	44.5	44.2	30.6	24.7	40.5	28.5	34.2	12.8	17.7	30.9
Cheyenne	47.4	48.1	38.0	29.3	43.1	24.0	31.8	14.0	13.7	32.2
Turkey	42.6	44.8	28.9	26.6	36.7	20.6	31.4	14.6	12.7	28.8

mercial varieties having considerable resistance. While Nebred is not resistant to all forms of bunt, it is resistant to those forms now known to be present in Nebraska.

TABLE 2.—*Average bunt infection of five varieties of winter wheats grown in uniform winter wheat bunt nursery in the Great Plains area, 1932–37.*

Variety	Average percentage bunt infection (52 station years)
Nebred	2.1
Oro	5.1
Minturki	6.3
Cheyenne	43.7
Kharkof	45.1

Nebred is not considered resistant to stem rust, but it seems to be able to produce a fairly good crop of grain in the presence of rust. This is probably due in part to some degree of earliness and a tendency to become infected with rust a little later than some other varieties. The variety is susceptible to leaf rust.

The milling quality of Nebred is very good, and the flour gives a good loaf of bread, although there is a slight tendency for a yellow color to be present in some years.

The variety was named in 1938 and released to farmers for fall seeding. About 1,100 bushels were available and all of this was seeded.

PILOT, REG. NO. 322

Pilot (N. No. 1098, C. I. 11428) was developed in cooperative experiments of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the North Dakota Agricultural Experiment Station, as well as other cooperating state stations in the regional hard spring wheat improvement program. Pilot is the result of a Hope×Ceres cross made under the direction of the writer by E. R. Ausemus in 1926 at the Northern Great Plains Field Station, Mandan, N. Dak. The selection resulted from stem rust inheritance studies made from the cross by Clark and Ausemus in F_3, 1928, and the strain entered nursery experiments in all North Dakota stations in 1931 and the Uniform Regional Nursery in 1932. It is the only hybrid strain that has been continued in that nursery from its start in 1932 to 1938, during which period 94 strains have been tested.

Results have been obtained from the regional nursery on Pilot wheat at from 9 to 17 stations for seven years, or a total of 96 station years. The strain N. No. 1098 entered plat experiments at the four North Dakota stations in 1933 and was a uniform variety at all cooperating stations in the spring wheat region by 1936. It has been included in the plat experiments for from 3 to 6 years at 19 stations, or a total of 76 station years. Its best performance has been at the Langdon Substation, Langdon, N. Dak., where, at the request of the writer, reselections were made in F_8, 1933, by G. S. Smith to provide foundation stock seed. From more than 100 selections grown in 1934, 80 were composited for increase and this stock was known as N. No. 1098-A.

In the bad rust year of 1935, many of the individual selections were still under test at Langdon and nine of the most resistant and highest yielding strains were composited as N. No. 1098-B. This seed is being increased separately at Langdon and about 80 bushels are now available. Certain of these nine strains have been continued in experiments at Langdon and Fargo and strains -13, -18, -28, and -59 appear more promising than the N. No. 1098-B. The seed of N. No. 1098-B was substituted for the regular N. No. 1098 for the Uniform Regional Nursery in 1936 and in plat experiments at most stations in 1938. One of the single line strains, -28, was substituted for the N. No. 1098-B in the Regional Nursery in 1938. Either it or a better one of the single line strains continued will be increased for the future distribution of Pilot seed. In the meantime, a bulk of the original N. No. 1098 and the N. No. 1098-A has been increased by E. J. Taintor, Superintendent of the Walsh County Agricultural and Training School, Park River, N. Dak., and from 78 acres grown in 1938 approximately 2,000 bushels are available for seeding in 1939.

Pilot is an awned spring wheat with white glabrous glumes and midsized (Cereslike) hard, red kernels. Its superior characters are resistance to both stem and leaf rust and to bunt. It is a high yielding wheat, especially in northeastern North Dakota, and has exceptionally good milling and bread making properties, ranking first among the new hybrid strains tested by the U. S. Dept. of Agriculture.[5] Messers. J. A. Clark and Glenn S. Smith applied for its registration.

Yields and other data upon which registration was based are shown in Tables 3 and 4.

THORNE, REG. NO. 323

Thorne (T. N. 1006, C. I. 11856) was developed by the Ohio Agricultural Experiment Station from a Portage×Fulcaster cross made at Columbus in 1917 by L. E. Thatcher. The selection known as T. N. 1006 was made in 1924 and reselections for furnishing foundation stock seed were made in 1934. In 1936, in the neighborhood of 200

[5]Fifield, C. C., and Clark, J. A. Milling and baking experiments with hard red spring wheats, 1929–35. 28 pp. June 15, 1936. [Mimeographed.] For further information on Pilot wheat (Hope×Ceres, N. No. 1098, C. I. 11428) see the annual mimeographed reports, "Results of spring wheat varieties grown in cooperative plot and nursery experiments in the spring wheat region," by J. A. Clark from 1932 to 1937.

TABLE 3.—*Yield per acre, stem rust, and quality data on Pilot and standard varieties grown in nursery and plat experiments at the Langdon Substation, Langdon, N. Dak., 1931–38.*

Experiment and variety	1931	1932	1933	1934	1935	1936	1937	1938	Av.
				Yield per acre, bu.					
Nursery:									
Pilot (new)	25.2	27.7	17.9	19.2	14.3	9.9	28.4	22.9	20.7
Ceres	16.8	27.0	19.1	19.6	0.7	12.5	12.9	3.2	14.0
Marquis	12.0	25.7	18.9	18.8	0.0	10.5	7.7	0.0	11.7
				Stem rust, %					
Pilot (new)	2	T	0	T	25	0	5	1	4
Ceres	25	15	3	7	65	0	65	85	33
Marquis	60	30	12	15	100	0	80	100	50
				Yield per acre, bu.					
Plats:									
Pilot (new)	—	—	16.0	24.1	18.7	6.5	31.6	33.7	21.8
Hope	—	—	15.0	21.3	15.5	5.8	30.1	30.0	19.6
Thatcher	—	—	15.8	25.0	17.3	5.7	26.2	22.4	18.7
Ceres	—	—	20.4	23.8	3.3	5.7	18.9	8.6	13.5
Marquis	—	—	19.8	24.6	0.4	6.2	16.7	4.8	12.1
Reward	—	—	14.0	15.9	2.4	0.7	19.4	10.4	10.5
				Stem rust, %					
Pilot (new)	—	—	0	1	15	0	10	5	5
Hope	—	—	0	0	T	0	0	0	0
Thatcher	—	—	0	1	10	0	10	5	4
Ceres	—	—	1	5	80	0	65	85	39
Marquis	—	—	3	15	95	0	80	100	49
Reward	—	—	2	7	100	0	85	95	48
				Test weight, lbs.					
Pilot (new)	—	—	60.0	58.5	48.5	58.0	60.6	58.2	57.3
Thatcher	—	—	59.5	59.0	51.0	55.5	59.1	57.5	56.9
Hope	—	—	58.0	58.0	48.5	56.5	58.0	55.5	55.8
Ceres	—	—	61.0	60.5	41.5	59.0	54.9	43.0	53.3
Marquis	—	—	60.0	60.0	40.5	58.5	53.0	42.5	52.4
Reward	—	—	63.0	61.5	42.0	56.0	60.0	53.5	56.0
				Crude Protein Content, %					
Pilot (new)	—	—	14.8	15.6	16.0	18.3	15.2	14.5	15.7
Thatcher	—	—	14.9	15.7	15.7	18.6	14.6	14.0	15.6
Hope	—	—	14.3	14.7	16.0	—	—	—	—
Ceres	—	—	13.9	15.5	15.8	18.0	13.0	—	—
Marquis	—	—	13.7	14.1	—	18.0	—	—	—
Reward	—	—	16.0	16.3	—	—	—	—	—
				Loaf volume, basic bake, cc					
Pilot (new)	—	—	653	693	571	699	650	643	652
Thatcher	—	—	630	670	577	672	625	629	634
Hope	—	—	577	531	543	—	—	—	—
Ceres	—	—	577	568	697	835	592	—	—
Marquis	—	—	583	513	—	723	—	—	—
Reward	—	—	633	656	—	—	—	—	—
				Loaf volume, commercial bake, cc					
Pilot (new)	—	—	—	—	688	766	715	758	732
Thatcher	—	—	—	—	673	764	670	737	711

TABLE 4.—*Average yield from plat experiments of Pilot, Thatcher, Ceres, Reward, and Marquis wheats at 19 experiment stations in 7 states during 3- to 6-year periods.*

State and station	No. years	Pilot	Thatcher	Ceres	Reward	Marquis
North Dakota:						
Langdon	6	21.8	18.7	13.5	10.5	12.1
Fargo	6	24.4	24.4	20.3	19.3	15.4
Mandan	6	9.8	10.9	6.9	7.1	4.9
Dickinson	6	7.9	6.6	6.7	4.7	5.1
Average	24	16.0	15.2	11.9	10.4	9.4
Minnesota:						
St. Paul	4	18.2	21.5	14.4	20.7	10.4
Waseca	4	32.1	30.5	21.1	23.8	13.8
Morris	4	25.0	28.5	15.2	19.9	11.0
Crookston	4	21.8	21.0	13.3	16.1	8.2
Average	16	24.3	25.4	16.0	20.1	10.9
South Dakota:						
Brookings	5	19.0	21.4	12.6	14.6	9.6
Highmore	3	6.6	7.1	7.2	5.3	4.1
Newell	3	11.2	13.6	11.0	6.8	11.1
Average	11	13.5	15.4	10.7	9.9	8.5
Montana:						
Bozeman	3	57.2	62.4	58.3	45.3	57.9
Moccasin	4	12.5	14.0	13.7	12.0	12.5
Havre	3	8.9	9.6	10.4	9.0	7.8
Average	10	24.8	27.2	26.1	21.1	24.7
Nebraska:						
Lincoln	3	10.2	11.0	10.5	10.1	5.7
North Platte	3	7.1	8.0	9.1	6.5	5.8
Alliance	3	9.2	9.8	9.9	9.9	6.8
Average	9	8.8	9.6	9.8	8.8	6.1
Wyoming:						
Sheridan	3	19.8	21.8	21.7	19.6	16.9
Colorado:						
Akron	3	9.8	10.3	9.9	12.9	8.2
Region:						
Weighted average	76	17.6	18.3	14.5	14.1	11.4

lines similar in appearance and performance were bulked together and increased as Thorne wheat.

Thorne is an awnleted, brown glumed variety of soft red winter wheat. It has the appearance of Portage (Poole) and the straw is exceptionally stiff, being superior to Trumbull in this important respect. The head is carried erect, and the grain is reasonably plump. In quality, it is similar to Trumbull and Fulhio, and acceptable to the soft wheat millers. Thorne has outyielded Trumbull and Fulhio in

TABLE 5.—*Comparative yields of Thorne, Trumbull, and Fulhio wheats at Wooster and average of Ohio stations, 1926–38.**

Variety	Wooster (Wayne County)							
	1926	1927	1928	1929	1930	1931	1932	1933
Thorne	61.5	46.9	44.8	44.0	43.6	50.8	26.9	52.0
Fulhio	58.7	46.9	34.8	40.5	40.7	47.4	22.8	48.7
Trumbull	56.3	45.7	32.8	40.3	39.8	47.3	21.5	51.5
Variety	1934	1935	1936	1937	1938	Total years	Average	Percentage of Trumbull
Thorne	—	—	40.1	49.6	58.5	11	47.2	113.2
Fulhio	—	—	—	37.2	52.7	10	43.0	103.1
Trumbull	—	—	35.6	37.1	51.1	11	41.7	100.0

Variety	Average of all stations							
	1926	1927	1928	1929	1930	1931	1932	1933
Thorne	61.5	46.9	44.8	33.7	31.4	46.9	28.5	36.5
Fulhio	58.7	46.9	34.8	32.0	31.5	44.3	26.2	32.7
Trumbull	56.3	45.7	32.8	31.2	30.2	44.2	24.9	32.8
Variety	1934	1935	1936	1937	1938	Total years	Average	Percentage of Trumbull
Thorne	34.7	39.4	33.2	33.5	42.1	107	36.7	108.9
Fulhio	32.4	36.0	—	32.4	36.9	100	34.4	102.1
Trumbull	33.1	36.4	29.8	31.6	37.8	107	33.7	100.0

*For further information on Thorne wheat, see Special Circular No. 55, Thorne Wheat, Ohio Agr. Expt. Sta., September 1938.

tests at 15 stations. The yield results, which are the basis for registration, at Wooster and the average for all 15 stations in Ohio are given in Table 5. C. A. Lamb, who made the selection, applied for the registration of Thorne wheat.

NOTE

PERFECT-FLOWERED BUFFALO GRASS (*BUCHLOE DACTYLOIDES*)

BUFFALO grass with perfect flowers borne on the staminate inflorescence was found in June, 1938, at College Station, Texas. Since this grass is one of the most important range grasses in Texas, the Agricultural Experiment Station started an intensive study with it in December, 1936. At that time, 1,000 seeds secured from Temple in the blackland region and a like number secured from Chillicothe in the rolling plains in western Texas were planted in flats in the greenhouse at College Station. Since there is a great deal of difference in the appearance of the plants from the two regions, plants from the blacklands have been termed the "Temple" strain and those from western Texas the "Chillicothe" strain.

FIG. 1.—Normal staminate spike at the time of anthesis (natural size).

The germination was 46.6% for the Temple strain and 52.1% for the Chillicothe strain. These seedlings were transplanted into pots and, when fully established, 300 of the most vigorous plants of each strain were set in plats 4 feet square in the grass nursery. Exact and comprehensive notes have been kept of each individual plant and data have been secured on characters such as rate of growth, width and length of leaf, length of internode, winterhardiness, drought resistance, length of seed stalk of both male and female, and a number of other characteristics.

In making examinations of these data, we came upon a plant which produced perfect flowers on what was normally the staminate inflorescence. (See Figs. 1 and 2.) Later four other plants of a like nature were found. Microscopic examination shows beyond a doubt that the flowers are truly perfect. Examination of matured florets from these plants revealed several which produced what appear to be fully developed caryopses, though much smaller than normal seed produced by the female plant. The viability of these seeds has not yet been determined. That the pollen is functional is demonstrated by the fact that normal seeds have been obtained from crosses in which the perfect-flowered plant served as the pollen parent. Plant No. 534 is staminate and practically all of the inflorescence shows this peculiarity. Plant No. 45 was first recorded as a monoecious plant as both male

FIG. 2.—Staminate spike showing both anthers and stigmas at the time of anthesis (enlarged 4 times).

and female inflorescences were present. Later examination showed that some of the staminate spikes contained perfect flowers.

Just what practical application can be made of this discovery is problematical, but it is reasonable to assume that if this type of plant can be propagated, the question of gathering seed would doubtless be greatly simplified. Further intensive studies are being made with the plants, among them being their use as parents in controlled crosses. —R. L. HENSEL, *Texas Agricultural Experiment Station, College Station, Texas.*

BOOK REVIEWS

MICROPEDOLOGY

By Dr. Ing. Walter L. Kubiena, Ames, Iowa: Collegiate Press, Inc. XVI+243 pages, illus. 1938. $3.

THIS book represents the lectures the author gave as guest Professor of Soil Morphology at the Iowa State College during the year 1937 and is the result of his nine years' experience in the adaptation of the microscope to soils investigations. The book assumes a knowledge of general soils, soil microbiology, and microscopy and is devoted to the fundamental principles of microscopic pedology.

The material is presented in four parts. Part I presents the principles of micropedology, uses and development of microtechnic in other natural sciences. Part II treates of the technic of micropedology with chapters on incident light microscopes, the soil microscope, performance of micromanipulations, microscopic field investigations, soil sampling, soil preparations, fabric reactions, optical methods, and microchemical methods. The detailed procedures for micromanipulations are well illustrated by excellent drawings and photographs. Part III develops the principles of soil fabrics or the arrangement of the constituents of a soil in relation to each other. Part IV deals with biological soil microscopy by which is understood a study of living things in the soil and their activity in the microscopic dimensions as perceived by direct observation.

Dr. Kubiena has introduced a new concept in soil fabrics which is most interesting and promises to be of large value in the study of the genetic relationships of soils. (F. B. S.)

STATISTICAL METHODS

By George W. Snedecor. Ames, Ia.: Collegiate Press. XIII+388 pages, illus. 1938.

THIS work could very properly be called an enlarged edition because, while the book has been increased 47 pages, the amount of revision of the original text is relatively small. A number of sections have had additions of one or more paragraphs, but the bulk of new material is contained in 13 extra sections inserted at appropriate places throughout the book.

The following are the titles of the added sections: Ratios and percentages, rates and percentages, size of sample, regression and rates, correlation between mean and variance, proportional subclass numbers, disproportional subclass numbers, randomized blocks in several localities or seasons, perennial plants in randomized blocks, four or more variables in a single group, calculation of regression with four variables, tests of significance for betas.

While the additions to sections of the original edition are too numerous to discuss, mention should be made of the inclusion of methods for calculation of missing data and the figure in section 11.5. Table 13.5 has been changed from "The 5% and 1% Points for Multiple

Correlation Coefficients with Three Variables" to "The 5% and 1% Points for *r* and R."

All of this new material will be welcomed by agricultural and biological workers and increases the value of this useful book. The discussions relative to percentages, rates, and ratios are especially valuable in pointing out the possibility of misinterpretation of results where the data are expressed and analyzed in these forms. "Percentages are fruitful sources of error" so Dr. Snedecor has performed a service in calling the attention of workers to pitfalls to be avoided. The comments given in the review of the original edition (Vol. 29, page 1033, of this JOURNAL) apply with even more force to the revised edition. (F. Z. H.)

PLANT PHYSIOLOGY

By Nicoloi A. Maximov. New York: McGraw-Hill Book Co. Ed. 5 (Second English translation). XXII 473 pages, illus. 1938. $4.50.

THE text of the new edition of this book has been completely re-arranged. The major part of the discussion has been re-written and the results of recent new research has been included. Illustrations are ample and have been taken, in general, from publications in English.

The book fills a need primarily for class room use and the teaching of plant physiology in agricultural institutions. It meets this need well by the manner in which the text is arranged and by the use of agricultural plants as material. The opening chapters acquaint the student with the general nutrition and growth of plants. These chapters deal with the physico-chemical organization of the plant, including its chemical composition and basic metabolism, respiration, growth, carbon and nitrogen assimilation, absorption of mineral elements, water relations, and translocation of substances.

The closing chapters, as well as the foregoing, deal with the plant as a unit organism and bring out the problems that have a more direct bearing on agricultural production and practice. Herein are explained the resistance of plants to unfavorable environmental conditions, interrelations between different parts of the plant, vegetative propogation, physiology of the development of plants and processes during flowering and ripening of fruits and seeds, and the seasonal phenomena in the life of plants. A complete picture of plant life starting in with the germination of the seed and ending with processes dealing with reproduction and maturation of seeds is presented to the student.

The new edition should receive an even wider acceptance than previous editions by students and teachers of plant physiology in agricultural institutions. (O. A. R.)

FELLOWS ELECT FOR 1938

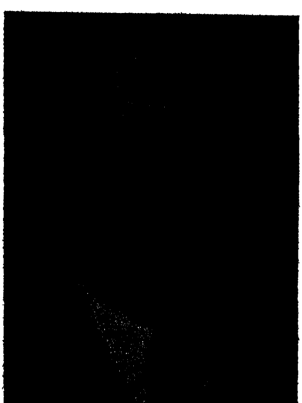
WILLIAM HENRY PIERRE

William Henry Pierre, Iowa State College, Ames, Iowa. Born on a farm near Brussels, Wisconsin, August 2, 1898. B.S.A., University of Wisconsin, 1921; M.S., 1923; Ph.D., 1925. Assistant soil surveyor, Wisconsin State Soil Survey, 1919–1921; assistant soil surveyor, South Dakota State College, 1921–1922; associate soil chemist, Alabama Agricultural Experiment Station, 1925–1929; associate professor of agronomy, University of West Virginia, 1929–1936; professor of agronomy and head of department of agronomy and genetics, 1936–1938; professor of agronomy and head of department of agronomy, Iowa State College, 1938–.

Member of A.A.A.S., American Chemical Society, American Society of Plant Physiologists, Soil Science Society of America, International Society of Soil Science, American Society of Agronomy.

Dr. Pierre has been an active member of the Society, having served on various committees and having taken part in many of its annual programs. In 1931 he received the Chilean Nitrate of Soda Research Award. His most important scientific contributions have dealt with soil acidity, methods of determining the acid and base balance of fertilizers, buffer action of soils, relation of base saturation of soils and soluble aluminum to plant growth, and pasture management. His method of determining the acid and base balance of fertilizers was recently adopted as official by the A.O.A.C., and the method has already been instrumental in helping to bring about the use of fertilizers with a lower-acid forming tendency. Besides his research on specific problems and his teaching activities, Dr. Pierre has been actively interested in the practical problems of soil management and agriculture in general.

IDE PEEBLES TROTTER



Ide Peebles Trotter, Head of the Department of Agronomy, Texas A. & M. College. Born at Brownsville, Tenn., December 12, 1895. B.A., Mississippi College, 1915; B.S., Mississippi A. & M. College, 1918; M.S., Mississippi A. & M. College, 1920; graduate work, University of Missouri, 1924–27, and University of Wisconsin, 1930–32; Ph.D., University of Wisconsin, 1933. Gamma Sigma Delta; Epsilon Sigma Phi; Alpha Gamma Rho; Pi Gamma Mu; Alpha Kappa Delta; Gamma Alpha. Extension Assistant Professor of Field Crops, University of Missouri, 1923–36; member of Missouri Cotton Allotment Board, 1933–34; since September 12, 1936, Head of the Department of Agronomy, Texas A. & M. College.

Dr. Trotter at Missouri was interested in the broad field of agronomy. His special employment was in extension teaching. For many years he labored constructively in the promotion of improved crop practices and soil management, and his efforts have left a lasting impression on Missouri agriculture.

CHARLES JULIUS WILLARD

CHARLES JULIUS WILLARD, Professor of Agronomy, Ohio State University, and Associate in Agronomy, Ohio Agricultural Experiment Station. Born at Manhattan, Kansas, February 14, 1889. B.S., Kansas State College, 1908; B.S.A., University of Illinois, 1910; M.S., University of Illinois, 1917; Ph.D., Ohio State University, 1926. Sigma Xi; Phi Kappa Phi; Alpha Zeta; Gamma Sigma Delta. Farmer, Brodford, Kansas, 1910–13, and Williamsburg, Virginia, 1913–16; Assistant Professor of Farm Crops, Ohio State University, 1917–26; Professor of Farm Crops, 1926–33; Professor of Agronomy, 1933—; Associate in Agronomy, Ohio Agricultural Experiment Station, 1926—.

Professor Willard is widely and favorably known for his contributions to the knowledge of life histories, ecology, physiology, comparative characteristics and responses of many forage crops. His studies of the life history phenomena and management of sweet clover were prime factors in raking that plant from the category of a "weed" to a forage and soil improvement crop of high rank.

Similarly his very extensive studies with alfalfa have provided a much-needed picture of its growth and management under humid conditions. Numerous investigations with the true clovers, of hay making problems, of life histories and control of weeds, and his analyses and investigations of factors and problems in securing successful seedings of forage crops, have earned him an enduring place in the agriculture of Ohio and the nation. He is author and co-author of an extensive and highly creditable series of publications which have been prepared with the utmost regard for adequacy and accuracy.

An energetic, analytical, active, cooperative, stimulating worker and coworker with intense interest in application and action programs as they are affected by and affect his studies. A conscientious teacher, whose former students long appreciate the wide extent and the thoroughness of his knowledge.

MINUTES OF THE THIRTY-FIRST ANNUAL MEETING OF THE SOCIETY

THE Thirty-first Annual Meeting of the Society was held in the Mayflower Hotel in Washington, D. C., November 16, 17, and 18. There were 653 registered at the meetings and considerably more than 700 in attendance at the sessions.

The general meeting of the Society was held jointly with the Soil Science Society of America on Thursday morning, November 17, President Truog and President A. M. O'Neal of the Soil Science Society presiding. The application of agronomy in farm planning was discussed by Dr. E. J. Utz of the Soil Conservation Service and "Soils, Crops, and People" was the subject of a paper by Dr. M. L. Wilson, Undersecretary of Agriculture.

The annual dinner was held on Thursday evening, with the address of the President, "Putting Soil Science to Work", as the feature of the occasion.

The Soil Science Society of America held meetings on Wednesday, Thursday afternoon, and Friday with programs on soil physics, soil chemistry, soil microbiology, soil fertility, soil morphology, and soil technology. The Crops Section had programs arranged on breeding, genetics and cytology, physiology, morphology and taxonomy, and miscellaneous subjects. Twenty-four half-day sessions were held in which 121 scientific papers were presented.

The Auditing Committee appointed by President Truog consisted of Dr. H. J. Harper and Dr. M. T. Jenkins. The Nominating Committee consisted of President Truog, Chairman, Dr. P. V. Cardon, Professor W. O. Collins, Dr. W. H. Pierre, and Professor A. T. Wiancko.

FELLOWS

Vice-President Garber announced the Fellows Elect and presented the diplomas. Those elected were Dr. W. H. Pierre, Dr. Ide P. Trotter, and Dr. C. J. Willard. (See pages 1047 to 1048.)

OFFICERS' REPORTS

REPORT OF THE EDITOR

TO SUMMARIZE briefly, the 1938 volume of the JOURNAL will not present any very marked differences from the 1937 volume, except that we have not fared quite so well this past year in respect to advertising, probably due to the general tightening up on such expenditures all along the business front. While our income from advertising has never been embarrassing, it is an important item in helping to meet certain overhead costs involved in JOURNAL publication and we take this opportunity to acknowledge our indebtedness to those advertisers who have patronized the JOURNAL through good times and bad and to point out to potential advertisers that the JOURNAL is well worth their consideration.

A total of 148 papers have been submitted to us during the past year. Of this number, 116 will have appeared in the JOURNAL with the publication of the December number. By way of record, it might be mentioned that of this 116

papers, 12 were presented at the annual meeting last year, including the two papers given on the general program, and one is the address of the President to which you have just listened and which will appear in the December JOURNAL.

We have 12 papers on hand, either awaiting publication or in the hands of reviewers, and 20 papers were returned to the authors for one reason or another. In addition, the 1938 volume will include 17 notes and 24 book reviews.

So much, then, for the make-up of Volume 30, except to express again, as we have in previous reports, our indebtedness to those who serve the JOURNAL and the Society so faithfully and so conscientiously in reviewing the papers submitted to us for publication.

One important responsibility was added to our office during the past year in the transfer of the stocks of the proceedings, journals, bulletins, etc., of the several agronomic organizations represented here tonight. In other words, we now have under one roof in Geneva, N. Y., all of the surplus copies of the JOURNAL of the American Society of Agronomy, the BULLETIN of the American Soil Survey Association, the PROCEEDINGS of the First International Congress of Soil Science, and the PROCEEDINGS of the Soil Science Society of America. These stocks are stored in a semi-fireproof building which, in turn, is protected with a sprinkler system, and are covered with a comprehensive insurance policy against loss from fire or damage from smoke or water, for as you will note from figures which appear in the Treasurer's report, these reserve stocks represent a very considerable potential income.

This change has necessarily incurred a considerable increase in the clerical work of the Editor's office. Since we assumed this duty early in the year, we have filled to date 5 orders for sets of the PROCEEDINGS of the First International Soil Science Congress, 13 orders for BULLETINS of the Soil Survey Association, 175 orders for back numbers of the JOURNAL of the American Society of Agronomy, and 223 orders for the PROCEEDINGS of the Soil Science Society.

We have now completed ten volumes of the JOURNAL since the publication in 1929 of the cumulative subject and author index for the first twenty volumes. A cumulative index of Volumes 21 to 30, inclusive, is ready to go to the printer, or will be with the paging of the December issue, and we wish to recommend to the Executive Committee at this time that this index of Volumes 21 to 30 be published as soon as possible. Following the procedure adopted with the publication of the index for the first twenty volumes of the JOURNAL, we recommend further that this new index be offered for sale by the Society at a price sufficient to meet the cost of publication and mailing.

I should like to close this report with a word of appreciation for one who from the founding of this Society down to the day of his death a few weeks ago maintained an active interest in all things pertaining to agronomy and who was particularly helpful in his unfailing interest in the JOURNAL. I refer to Dr. T. L. Lyon, for many years Chairman of the Editorial Advisory Committee. His counsels aided us immeasurably in weathering many difficult situations confronting the JOURNAL in recent years. Doctor Lyon was also the Society's Historian, and to his successor in this office will fall the privilege of inscribing his name high among those whom the Society would honor.

Respectfully submitted,
J. D. LUCKETT, *Editor*.

REPORT OF THE SECRETARY

THE membership changes in the Society since the last annual report are summarized briefly as follows:

Membership last report		1,213
New members, 1938	145	
Reinstated members	37	
Total increase	182	
Dropped for non-payment of dues	134	
Resigned	27	
Died	4	
Total decrease	165	
Net increase		17
Membership, October 31, 1938		1,230

The subscription list has been increased during the year as the following figures will indicate:

Subscriptions, last report		649
New subscriptions, 1939	119	
Subscriptions dropped	108	
Net increase		11
Subscriptions, October 31, 1938		660

The paid up membership and subscription list by states and countries is as follows:

	Members	Subscriptions		Members	Subscriptions
Alabama	12	1	Nevada	2	1
Arizona	10	2	New Hampshire	3	1
Arkansas	12	3	New Jersey	16	3
California	35	10	New Mexico	7	2
Colorado	15	2	New York	50	15
Connecticut	11	3	North Carolina	16	3
Delaware	3	1	North Dakota	10	1
District of Columbia	77	5	Ohio	48	3
Florida	21	2	Oklahoma	14	5
Georgia	13	4	Oregon	12	2
Idaho	9	1	Pennsylvania	22	8
Illinois	50	11	Rhode Island	7	1
Indiana	25	3	South Carolina	17	2
Iowa	49	3	South Dakota	10	1
Kansas	46	2	Tennessee	14	2
Kentucky	11	5	Texas	47	8
Louisiana	16	3	Utah	14	7
Maine	5	1	Vermont	3	1
Maryland	17	5	Virginia	23	1
Massachusetts	9	3	Washington	21	4
Michigan	21	6	West Virginia	5	1
Minnesota	28	4	Wisconsin	36	1
Mississippi	11	4	Wyoming	6	1
Missouri	21	5			
Montana	8	5	Alaska	0	1
Nebraska	28	2	Hawaii	9	13

	Members	Subscriptions
Philippine Islands	1	2
Puerto Rico	4	3
Africa	4	24
Argentine	8	9
Australia	2	25
Brazil	1	5
British West Indies	1	1
Canada	20	42
Cuba	2	2
Ceylon	0	3
Chile	1	1
China	6	19
Columbia	1	1
Czechoslovakia	0	1
Denmark	2	1
Dutch East Indies	0	5
Egypt	2	1
England	0	15
Estonia	0	1
Fed. Malay States	1	4
Fiji	0	1
Finland	0	1
France	1	13
Germany	3	10
Greece	3	2
Haiti	1	0
Holland	2	2
Honduras	2	1
Hungary	1	0
India	4	21
Indochina	0	1
Ireland	0	2
Italy	0	10
Japan	3	86
Jugoslovia	0	2
Mauritius	0	1
Mesopotamia	1	1
Mexico	2	1
Morocco	0	1
New Zealand	0	5
Norway	0	2
Nova Scotia	1	0
Palestine	2	0
Panama	1	0
Persia	1	0
Peru	0	4
Poland	0	2
Portugal	0	4
Roumania	0	1
Scotland	3	1
Siam	2	1
Spain	0	1
Sweden	0	4
Switzerland	1	0
Turkey	1	0
Uruguay	1	0
U. S. S. R.	7	84
Wales	0	3
	1,074	617

The number dropped for non-payment of dues is smaller than it was last report and represents largely those who have switched from the JOURNAL to the PROCEEDINGS. The number resigned this year was exactly the same as the number resigned last year. The large drop list among the subscriptions came principally from China and Japan. The list of paid up members and subscriptions shows that we have 156 members and 43 subscriptions whose dues are in arrears. Notices and bills have been sent to all of these. We hope they will pay their dues and continue with the Society.

The special representatives of the Society have been of material assistance in bringing in new members during the year. Special mention should be made of the efforts of Doctors Aamodt, Keim, Trotter, Myers, Obenshain, Sturgis, and H. K. Wilson for the aid they have given the Society in this work. The Society is very greatly indebted to these men and all others who have given us help during the year and we want to thank you.

The work in the Secretary's office has increased enormously over what it was a few years ago. The Treasurer's report this year shows about 25% increase in the funds handled over that of last year. All publications of the Society have been concentrated at Geneva and this will permit us to give you much more efficient service than formerly when these publications were located at several different places. However, it does require some time to relay your orders to Geneva and some delay is necessary in making shipment. We have tried to keep things moving but when delay has been occasioned you have been patient and charitable and we appreciate it. I am especially grateful to the officers and members of the Society for their splendid cooperation in handling the details and arrangements for the program and annual meeting. To you credit is due for the measure of success we have made.

F. B. SMITH, *Secretary*.

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year November 1, 1937 to October 31, 1938.

RECEIPTS

Miscellaneous	$ 208.44
Advertising income	618.07
Reprints sold	1,584.17
Journals sold	183.33
Subscriptions, 1938	2,452.78
Subscriptions, 1937	59.95
Subscriptions, 1938, new	589.22
Subscriptions, 1939	165.20
Dues, 1938	4,135.00
Dues, 1937	233.00
Dues, 1938, new	750.02
Dues, 1939	109.50
Sale of Soil Survey Association Bulletins	44.85
Miscellaneous, S. S. S. A.	333.94
Sale of Proceedings, Vol. I, 1936	597.32
Dues and subscriptions, S. S. S. A., 1938	2,813.25
Dues and subscriptions, S. S. S. A., 1939	18.50
Membership only, S. S. S. A., 1938	41.50
Membership only, S. S. S. A., 1939	1.50
International Society of Soil Science endowment fund	2,789.32
Sale of Proceedings First International Congress of Soil Science	37.70
Fees, I. S. S. S., 1938	707.40
Fees, I. S. S. S., 1938, new	95.00
Fees, I. S. S. S., 1937	34.85
Fees, I. S. S. S., 1939	5.00
Total receipts	$18,608.81
Balance in cash, November 1, 1937	3,117.61
Total income	$21,726.42

DISBURSEMENTS

Printing the Journal, cuts, etc	$ 8,758.98
Salary Business Manager and Editor	738.89
Postage (Business Manager and Secretary)	186.75
Printing, miscellaneous	461.36
Express on Journals and Proceedings	32.39
Mailing Clerk and stenographic	901.63
Refunds, checks returned, etc	151.43
Miscellaneous, expenses annual meetings, freight and mailing publications	1,194.18
S. S. S. A. expenses, printing Proceedings, etc	3,401.07
I. S. S. S. expenses, fees to Dr. Hissink, etc	926.10
Purchase of savings bond, I. S. S. S. endowment fund	2,250.00
Total disbursements	$19,002.78
Balance on hand, November 1, 1938	2,723.64
Balance in Trust Certificates	410.88
Balance in Savings Bond	2,250.00
Total balance in account	5,384.52
Balance in cash on hand	2,723.64

F. B. SMITH, *Treasurer*

AUDITING COMMITTEE

The books were examined and all accounts found in order as reported by the Treasurer.

H. J. HARPER M. T. JENKINS

COMMITTEE REPORTS

BIBLIOGRAPHY OF FIELD EXPERIMENTS

THE Committee has compiled a bibliography of 65 titles of the more important contributions on the methodology and interpretation of results of field plat experiments, either reported since or not included in the revised bibliography previously published in the JOURNAL (Vol. 25:811–828, 1933; and the additions in Vol. 27:1013–1018, 1935; Vol. 28:1028–1031, 1936; Vol. 29: 1042–1045, 1937).

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F. R. IMMER H. M. TYSDAL
J. T. MCCLURE H. M. STEECE, *Chairman*

EXTENSION PROGRAM

THE Committee suggests that each year as the chairmen of the soils and crops sections of the American Society of Agronomy contact workers in the various states and in the U. S. Dept. of Agriculture with regard to subjects for presentation before the meetings of the Society, that they be requested to ascertain if the particular piece of investigational work to be reported upon is developed to the point where it is ready for practical application.

If the work is ready for application, we suggest that an extension worker present the extension application as a part of the same program.

We also suggest that every other year the extension agronomists hold a half day session on problems related to the application of their programs in the field.

E. R. JACKMAN J. S. OWENS
EARL JONES W. F. WATKINS
J. C. LOWERY O. S. FISHER, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

THREE varieties of wheat and three varieties of oats were registered during the year. The wheat varieties are as follows:

Nebred, Reg. No. 321, developed in cooperative experiments at the Nebraska Station.

Pilot, Reg. No. 322, developed in cooperation with the stations in the Northern Great Plains.

Thorne, Reg. No. 323, developed by the Ohio Agricultural Experiment Station.

The oat varieties are as follows:

Fulton, Reg. No. 84, developed in cooperative experiments at the Kansas Station.

Carleton, Reg. No. 85, developed in cooperative experiments at the Oregon Station.

Bannock, Reg. No. 86, developed in cooperative experiments with the Idaho Station.

Cooperation in each instance involved the U. S. Dept. of Agriculture and the stations named.

During the year the Committee gave further consideration to the preparation of standards for the registration of grain sorghums, which registration has already been approved by the Society. Preliminary consideration was given to plans for the registration of alfalfa, these plans to be submitted to the Society at a later date.

Description of the above varieties and the yield and other records that form the basis for registration will be published in the JOURNAL.

H. B. BROWN	H. K. HAYES	T. R. STANTON
J. ALLEN CLAREK	W. J. MORSE	G. H. STRINGFIELD
E. F. GAINES	J. H. PARKER	M. A. MCCALL, *Chairman*

PASTURE IMPROVEMENT

THE work of your Joint Committee on Pasture Improvement during the last year has centered upon activities designed to bring about fuller consideration of the comparative nutritive value and relative cost of forage and other crops.

To this end your Committee cooperated in the formulation of a program devoted to this subject in connection with the meetings of the American Association for the Advancement of Science held in Ottawa, Canada, last June.

As a result of that discussion it was deemed advisable to hold a round table discussion on the same subject as a part of the program of the American Society of Agronomy in Washington, D. C., November 18. The purpose of this round table was to consider the problems involved and to define a proposed procedure aimed at (a) the compilation of available data, and (b) at the clarification of the objectives of work remaining to be accomplished in this field. Discussion leaders represented the viewpoints of agronomists, animal and dairy production specialists, and extension workers.

The proposed joint plan of attack agreed upon follows:

1. Invite full participation through properly designated individuals or committees of the American Society of Animal Production, the American Dairy Science Association, the American Society of Agronomy, and the Canadian Committee on Pasture and Hay.

2. Organize a central committee (a) to direct action, (b) act as clearing house, and (c) prepare joint reports for approval by respective organizations.

3. Secure approval by respective organizations of joint reports.

4. Prepare joint reports for suitable publication and distribution.

Suggestions were made that the American Farm Economics Association, the Soil Science Society, and possibly some other agencies be included.

P. V. Cardon was authorized to communicate with the various societies indicated and through them initiate joint action.

O. S. AAMODT
B. A. BROWN
R. D. LEWIS
D. R. DODD
H. D. HUGHES
GEORGE STEWART
PAUL TABOR
JOHN ABBOTT
P. V. CARDON, *Chairman*

STUDENT SECTIONS

WITH the recent addition of New Mexico State College and Virginia Polytechnic Institute, 18 institutions now have chapters of the Student Section of the American Society of Agronomy. A meeting of representatives of the various chapters has been arranged at the time of the Crops Judging Contest in connection with The International Grain and Hay Show in Chicago.

Fourteen essays on the subject "Contributions of Agronomic Research to Agricultural Progress" were judged by the following committee: A. L. Frolik, Karl S. Quisenberry, and Karl Manke of Nebraska; J. W. Zahnley of Kansas; J. B. Peterson of Iowa; and G. H. Dungan and O. H. Sears of Illinois.

The first three winners will receive expense money up to a total of $50 each to permit them to attend the International Grain and Hay Show in Chicago. In addition each man will receive an appropriate medal and a year's subscription to the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY. The winners of 4th, 5th, 6th, and 7th, places will receive cash prizes of $20, $15, $10, and $5, respectively.

The authors of the first ten papers in order are: Maurice Peterson, Nebr.; Hilbert A. Grote, Kans.; Ogden C. Riddle, Nebr.; Robert E. Daniell, Nebr.; Frank A. Fieber, Ill.; Noel Hanson, Minn.; J. Richard Moore, Kans.; Russell H. Gripp, Kans.; Harold H. Mies, Ill.; and A. J. Fisher, Ill.

It is recommended that the abstracts of the first three papers be published in the JOURNAL of the Society. The committee proposes that the Society continue to sponsor the essay contest during the coming year.

G. H. DUNGAN
A. L. FROLIK
J. B. PETERSON
J. W. ZAHNLEY
H. K. WILSON, *Chairman*

CONTRIBUTIONS OF ALFALFA RESEARCH TO AGRICULTURAL PROGRESS

By Maurice Peterson, Univ. of Nebraska

THE importance of alfalfa hay in the United States can be determined by observing the fact that it represents the greatest annual tonnage production of any kind of hay. Although attempts were made to grow alfalfa in colonial times, it really did not prove successful until 1854 when it was introduced into California from Chile. Acreage increased rapidly and within half a century it was grown throughout the United States where it was originally adapted. Since that time however, the acreage increase has been most rapid in the north where winter hardiness was a factor and in the east where unfavorable soil conditions were to be dealt with. This increase could not have been accomplished except for the research man.

The establishment of alfalfa on unadapted soils was important because the greatest need for this legume hay was in the eastern and northern dairy states where alfalfa was unadapted. One of the first pieces of research on alfalfa involved the discovery of the symbiotic relationship of bacteria and the legume plant. Upon this discovery was hinged the forthcoming work on bacterial strains, their acid tolerance, and the practical aspects of inoculation and of liming to reduce soil acidity. Although work on mineral deficiencies for alfalfa has not been extensive, it has nevertheless been responsible for the establishment of the crop on certain areas where it otherwise would not grow.

Many cultural practices have been found which helped greatly to increase the popularity of the crop. Seed bed preparation is an important problem in securing stands. The advisability of using a nurse crop depends upon the part of the country, season of the year, and other factors. The most popular nurse crops are wheat, oats, rye, flax, and barley. Application of lime and manure have helped greatly to secure stands in some localities.

Time of cutting and too frequent cuttings have been found to decrease winter hardiness and crop yields. This work has been substantiated by the plant physiologist relating to storage of organic food reserves, especially during the fall season. Winter protection afforded by fall top growth is a factor for reducing winter killing.

Crop sequence has an effect upon yields because of alfalfa's utilization of accumulated subsoil moisture which is usually not replaced for a period of many years under normal crop rotation in the dry farming areas. In areas of abundant winter rainfall, however, it has been found necessary to provide drainage to prevent killing out of stands.

Variety recognition has been comparatively recent. Most of the varieties grown at the present time are the results of testing of introduced and selected strains of alfalfa. Illustrations of this are Cossock, Ladak, Turkestan, and Grimm alfalfas. These varieties vary greatly in their desirable characteristics. The part of the country where a variety is used depends upon the limiting factor in crop production in that area. Some of the things varieties are selected for are superior yield and quality, wilt resistance, cold resistance, insect resistance and resistance to blackstem disease. Varieties or strains are now in existence which are strong in one or more of these factors. The plant breeder is now trying to recombine the desirable characters of two or more strains into one variety. Considerable recent work has been done along these lines and this introductory work has opened up a field with unlimited future possibilities.

CONTRIBUTIONS OF AGRONOMIC RESEARCH TO AGRICULTURAL PROGRESS

By Hilbert A. Grote, Kansas State College

PLANT research plays an important role in keeping mankind in stride with the ever varying traits of nature. Agronomic research workers have accomplished much in establishing a more stable agriculture and continuing it as such. Through introduction, selection, and crossing, adapted crops have been established in most sections of the country. New uses have been found for the old crops, as soybeans, now valuable for oil, food, and industrial purposes.

A phase of research being given much attention recently is that of weed control. The plant investigators are endeavoring to find the most successful and economical means of eradicating the more persistent weed pests. Much work is being

done at the present time on Field Bindweed, *Convolvulus arvensis L.*,. A comparatively few years ago this weed was of little importance, but it has been spreading at such an alarming rate that today it is considered the most troublesome of all weeds in many regions of the United States.

That this weed can be successfully eradicated has been definitely proved by experiments conducted at various experiment stations throughout the country. Clean cultivation is by far the most dependable and economical of all eradication methods now known.

The death of bindweed under fallow treatment is primarily due to a starvation process. When the above-ground parts of the bindweed plant are cut off, it is forced to draw upon the food reserves in the roots to produce a new top growth. When the cutting-off process is repeated each time before the top growth reaches the proper stage to replenish the supply, the food reserves are gradually exhausted. When cultivation at the proper intervals is continued long enough the death of the plant always results. Advantages of clean cultivation are that it is cheaper, that it usually increases the productivity of the soil, and it is more dependable than other treatments. Investigations show that bindweed may be eradicated for approximately ten dollars an acre, whereas, the cost of eradication by the use of sodium chlorate will range from thirty-six dollars to fifty-two dollars per acre. Practically all recent data show that bindweed may be successfully eradicated by one and one-half to two years of intensive cultivation.

The prime requisite of any implement used for eradicating bindweed by clean tillage is that it shall cut off all the plants underground. The best implements for cultivating are the duckfoot and blade type weeders. Duckfoot sweeps should overlap at least three inches, while with blades it should be five or six inches. The most common depth of cultivation is about four inches, however variations in depth have little influence on eradication. Best results were obtained when the bindweed was permitted to grow about eight days after each emergence. When this was done only fifteen cultivations were required to eradicate the bindweed.

Smother crops alone can rarely, if ever, be depended upon to eradicate bindweed, but when used in combination with clean cultivation have proved successful.

THE CONTRIBUTION OF RESEARCH IN BARLEY TO AGRICULTURAL PROGRESS

By Ogden C. Riddle, Univ. of Nebraska

BARLEY is grown principally in the Northern and Western states, but is becoming of increasing importance in southern United States and Canada. Production over this vast area has increased regional and local problems of production in number and complexity.

High yield is of primary importance, but may be difficult to obtain due to such adverse factors as drouth, cold, disease, insect damage or lodging. The importance of yield may be tempered somewhat by specific quality requirements for various uses. The job of the barley research worker has been, and is, to produce a barley that will give maximum yields of grain having the attributes of quality necessary for the use to which the barley of the region is to be put.

Production trends of the past few years indicate a normal production of 300,000,000 bushels as compared to 15,500,000 bushels in 1860. Since 1866, corn acreage has increased threefold, oats five fold, and barley acreage is thirteen times greater. This increase reflects the favorable regard of agriculture and industry for the crop and its products. Efforts by research workers to improve the quality

and yield of the crop have resulted in a product of greater utility for numerous manufacturing processes and a successful competitor with other crops as an economical feed producer.

About seventy per cent of the nations barley crop is used as feed. The most important single variety used for this prupose is Trebi. Trebi resulted from an individual plant selection. It was released to farmers in 1918 and grown on 2,224,000 acres in 1935.

The thirty per cent which is used for malting and its many subsequent products is produced largely in the upper Mississippi Valley region and California. Manchuria and Oderbrucker were first grown as the standard malting varieties in the upper Mississippi Valley region. From these two varieties, by breeding and selection, have been developed new varieties with added desirable characters such as smooth awns and added disease resistance. Velvet, Wisconsin Pedigree 38, Glabron, and Minnesota 184 are four such varieties which, in general, combine greater ease of handling with more assurance of a uniformly good malting barley than either Manchuria or Oderbrucker.

In California, the outstanding malting barley is Atlas, which originated as a selection from Coast in 1924. It excels Coast in being earlier, more lodge resistant, and higher yielding.

Improved winter varieties, such as Missouri Early Beardless, are increasing the acreage in the South for the production of grain, and as winter pasture and winter cover.

Disease control as a factor in higher yield and quality is being effected by chemical means and the production of resistant varieties.

Coordinated effort among producers and consumers, and the research workers in both fields, is leading to the development of standardizations of type and quality that will further increase the usefulness of the grain.

CORN HYBRIDS

IN LAST year's report your committee indicated that steps were being taken to organize a Corn Improvement Conference. This organization was perfected at the meeting of the Society in Chicago in December 1937 and includes the research and extension workers of the state agricultural experiment stations and the U. S. Dept. of Agriculture interested in corn improvement.

Last summer the directors of the Corn Belt experiment stations called a meeting of this conference at Madison, Wisconsin, on September 16 and 17. Action was taken at that time on a number of problems that have arisen in connection with the hybrid corn programs.

The organization of the Corn Improvement Conference has provided opportunity for concerted action by the group interested in hybrid corn. This committee, therefore, has had no occasion for any action during the past year and this is likely to be the situation in the future. It is suggested, therefore, that this committee be discontinued.

H. D. Hughes G. H. Stringfield
T. A. Kiesselbach M. T. Jenkins, *Chairman*

FERTILIZERS

Subcommittee on Fertilizer Application.—The Subcommittee on Fertilizer Application has continued its participation in the program of the National Joint Committee on Fertilizer Application. Fertilizer placement experiments sponsored

by this committee in 1938 numbered 144, included 26 different crops, 66 locations and 27 states. Although this program has been underway for 10 years, the variety and scope of the work has continued to expand each year. Plans for the future include additional placement studies on tree fruits and strawberries, the extension of placement studies to crops grown under irrigation, the development of more adequate machinery for experimental purposes, and investigations designed to clarify the fundamental principles affecting the relations of fertilizer placement to weather, soil conditions, root development and other factors.

R. M. SALTER, *Chairman*

Subcommittee on Fertilizer Ratios.—As a matter of expediency the fertilizer using territory was divided into three regions as follows; the southern states, the northeastern states, and the north central states.

In the northeastern states the agronomists and representatives of the industry are working toward the adoption of 12 ratios with a corresponding number of minimum grade fertilizers and six acceptable "high analysis" grades.

In 8 southern states a committee composed of representatives of the industry, the state commissioner of agriculture, and agronomists have agreed upon a list of grades which may be licensed for sale in the given state. No other grade may be licensed. This procedure has resulted in a material reduction in number of grades offered for sale. It is hoped other southern states will make an effort to reduce the number of grades recommended.

Agronomists of the north central states have agreed on 28 grades that will meet their requirements. Of these, 10 grades are recommended by 4 or more of the 8 states. No grade containing less than 10 units of plant food are recommended. Nineteen grades have been placed on the recommended list for Indiana, Ohio, and Michigan and fertilizer companies have voluntarily featured these grades in their advertising.

The cooperation of the fertilizer companies in forwarding the work of the committee is greatly appreciated.

C. E. MILLAR, *Chairman*

Subcommittee on Symptoms of Malnutrition in Plants.—The members of the Subcommittee on Symptoms of Malnutrition in Plants have carried on during the current year collecting suitable material for the proposed book illustrating distinctive symptoms on plants due to plant food deficiency. Two papers have been published by the chairman of the subcommittee. A review of the literature dealing with "Distinctive Plant Symptoms Caused by Deficiency of any one of the Chemical Elements Essential for Normal Development" was published in the *Botanical Review*. Technical Bulletin 612 of the U. S. Department of Agriculture entitled, "Symptoms on Field-Grown Tobacco Characteristic of the Deficient Supply of Each of Several Essential Chemical Elements" is just off the press. Other papers have been published by members of the subcommittee or are in the course of publication.

A day was devoted to a meeting of the subcommittee on October 13, 1938, at the Cosmos Club, Washington, D. C. Seven of the subcommittee members were present and one absent. Professor Salter and Mr. Smalley, Chairman and Secretary, respectively, of the committee on Fertilizers were in attendance. Mr. Callister of the Plant-Food Research Committee of the National Fertilizer Association was also present and discussed ways and means of publication. Considerable progress was indicated in the assembling of the material for the proposed book.

It was voted to prepare a preliminary draft by February 1, 1939, or as soon thereafter as possible of all available material. It was voted that all material to be included in the proposed publication be approved by directors of the agricultural experiment stations and bureau chiefs of the U. S. Department of Agriculture with which the various chapter authors are connected, or by directors of Agricultural Experiment Stations from areas with which the work is concerned if written by authors in commercial work.

An exhibit of available material is to be held in connection with meetings of the American Society of Agronomy, November 16–18, at the Mayflower Hotel, Washington, D. C.

It is recommended that the subcommittee be continued until the work assigned is completed.

J. E. McMURTREY, JR., *Chairman*

Subcommittee on Fertilizer Reaction.—The principal work of the Subcommittee on Fertilizer Reaction during 1938 has related to the evaluation of the availability of different forms of magnesium when used in complete fertilizers. This work was undertaken because the A.O.A.C. is trying to develop a chemical method for evaluating "available magnesium" in fertilizers. The choice of a chemical method will, of course, depend upon the availability to the crop of different sources of magnesium.

The subcommittee outlined a greenhouse and laboratory experiment that was designed to give data on the relative availability of magnesia in magnesium sulfate, hydrated dolomitic lime, selectively calcined dolomite, and different screen sized and sources of dolomitic limestone. Arrangements were made for the experiment to be conducted with five soils at the North Carolina Agricultural Experiment Station and with three soils by the Division of Soil Fertility, United States Department of Agriculture. The experiments are still in progress. The results from the first crop and set of soil samples were reported to the A.O.A.C. on November 14th by Doctors Dawson and Collins of the U. S. Department of Agriculture and the North Carolina Agricultural Experiment Station respectively.

Investigations similar to the above were conducted by Dr. J. B. Smith of the Rhode Island Agricultural Experiment Station. His data were also reported to the A.O.A.C. in a paper he presented as Associate Referee on Magnesium and Manganese in fertilizer.

Numerous field experiments relating to the relative efficiency of neutral and acid-forming fertilizers are being conducted in different states. The subcommittee, however, has made no special effort to initiate such experiments in the past year.

The past work of the committee is reflected in part in the greatly increased use of liming materials in fertilizers and the resultant decrease in the average equivalent acidity of American fertilizers. This has been shown by Mr. A. L. Mehring, U. S. Department of Agriculture, in a paper "Physiological Acidity of Commercial Mixed Fertilizers, 1929–1936". The tonnage of liming materials, mostly dolomitic limestone, used in the manufacture of fertilizers increased from 33,954 in 1929 to 98,654 in 1933 and 302,571 in 1936. The net equivalent acidity of American fertilizers decreased from 152 pounds calcium carbonate equivalent in 1933 to 19 pounds in 1936.

F. W. PARKER, *Chairman*

Subcommittee on Soil Testing.—Important features of work under way are:

(1) Soils for Check Determinations by Soil Testing Methods. It is expected that by the spring of 1939 about 16 soils will be available for distribution, with representative samples of various types and fertility levels from the southern, middle-Atlantic, northeastern and corn belt sections.

(2) Soil Testing by the Fertilizer Industry. A survey has been made, through the cooperation of the National Fertilizer Association. Sixty-four companies are doing soil testing work. A large majority of the companies feel that soil testing should be done by the official agencies in the states, rather than by the commercial concerns.

(3) Reports of Expansion in Soil Testing by Official Agencies. Several additional states (at least four) have taken up soil testing, and others are investigating methods with a view to offering this service if a satisfactory method is available for their conditions. Fertilizer control receipts are being used to finance the work in some states, and the interpretation of tests by control chemists may present a problem.

(4) Reports of Development in Methods. No important new developments in the main features of the various methods have come to our attention. Several promising refinements in technique have been worked out. Methods for minor elements (boron, zinc and copper) are still definitely in the preliminary stages of development.

Plans are suggested for a group of papers dealing with correlations of fertility levels, as shown by the various methods, with respect to crop adjustments on different soil types, to be presented at the A.S.A. meeting next year.

M. F. MORGAN, *Chairman*

WAYS AND MEANS OF INCREASING THE USE OF LIMESTONE IN THE SOIL CONSERVATION PROGRAM

THE following is an abstract of recommendations of a special committee of extension agronomists:

The Problem.—It is generally recognized that the extent to which a sound soil conservation and improvement program can be developed for the rotated and pasture land of the northeastern and north central states is limited chiefly by the speed with which we can get our acid land limed. A large percentage of the soil in the states east of the Great Plains is already acid.

A sound and permanent program of soil conservation must be built on the use of certain effective erosion-control and soil-building legumes, and it is a well-known fact that these legumes cannot be grown successfully on land of a certain degree of acidity. In order to bring back the productivity of both level and rolling land and to check erosion, good crops of legumes, such as sweet clover, red clover or alfalfa, must be grown either in rotation or in pastures and meadows.

Any attempt to side-step the liming of acid land in a long-time improvement program by promoting the growing of acid-tolerant legumes and grasses as soil-improving and soil-conserving crops is doomed to failure. The continued use of these crops to the exclusion of our more desirable soil-building legumes will only make a bad situation worse. The meager growth of these crops on strongly acid land will not materially build up the organic matter and nitrogen content of the soil nor will it furnish feed efficiently. As a matter of fact, the continued growing of these crops under strongly acid conditions means continued soil deterioration.

It should be kept in mind that this acid land will eventually have to be limed if it is to continue to be farmed. The longer liming is delayed, the more difficult it will be to finance the liming program from a decreasing income from the land.

The responsibility for the liming of these acid soils does not rest entirely on the farmer or land owner, but it is and should be of as much concern to the urban population as to the farmers. Plans for the solution of the problem must include the farms operated by the average or below average farmer as well as the farms operated by good farmers. The task is so big that concerted action by local, state and federal agencies is necessary and the educational agencies alone cannot accomplish the desired result.

Need for Liming.—While the U. S. Dept. of Agriculture and the colleges of Agriculture have, thru their extension services, stressed the need for limestone for the past 15 to 25 years, progress has been discouragingly slow. Agronomists of several states have prepared estimates of the lime needs of their states. Ohio needs two million tons of lime each year for the next 25 years in order to prepare Ohio farm land for growing satisfactory crops of clover and alfalfa. Fifty million tons are needed in Iowa. New York needs one million tons annually on the crop land to maintain the present lime content of the soil. An inventory of the lime requirements of Illinois farm land indicates a total need of approximately 50 million tons, while an average annual application of 2 million tons would be required simply to replace the lime lost each year through crop removal and leaching.

Credit for Purchasing Liming Materials.—The low productivity of much land, coupled with the drouth and low prices for farm products, during recent years, has made it impossible for many farmers to finance any extensive liming program without some assistance. At present there are no adequate local, state, or federal agencies from which the farmer can borrow for the purchase of limestone. The liming of acid soils will increase the soundness of the loans and greatly increase the possibility of prompt payments.

Production Credit Loans.—Loans from the Production Credit Corporation for the purchase of liming materials must now be repaid in one year, while substantial cash returns on an investment in liming materials may not be realized before the third or fourth crop after their application. Such loans should extend over a period of three to five years. We suggest that the Production Credit Corporation develop a plan for five-year loans to farmers for the purchase of liming materials.

In many cases a Commissioners loan would offer a more workable source of credit than the Production Credit loans. They would not be practical where the mortgage is held by an agency other than the Federal Land Bank because of the high costs of the appraisal and other costs. When the Federal Land Bank has the mortgage, the secretary of the local Loan Association could make the inspection for a small charge. Even when the farm already carries a Commissioners Loan a supplementary loan for liming materials might be made, if the borrower's past performance has been satisfactory. Commissioners loans may now carry money for the repair of buildings and this is a precedent for the practice of making such loans for the purchase of liming materials.

Federal Land Bank Loans.—When new Federal Land Bank loans are made on farms which need lime, the liming of the land might well be a requirement of the loan. The loan could be increased to care for the expense or a second short time loan might be drawn up to care for this purpose. Credit for liming the land should be extended in the case of farms on which the Federal Land Bank now holds mortgages. Other loaning agencies might well adopt these policies.

Other Sources of Credit.—Many farmers will not be able to borrow from any branch of the Farm Credit Administration or other credit agencies because of lack of collateral for loans. To meet this situation state legislation authorizing the County Commissioners or County Board of Supervisors to issue bonds to finance liming programs for such farms would help meet the situation. Money received from the sale of the bonds would be loaned to farmers who have no other source of credit. These loans might run for five years and be paid in five annual installments with the taxes on the farms.

Agricultural Conservation Program.—The soil-building practices under the Soil Conservation and Domestic Allotment Act have done much to encourage a sound soil conservation program. The limestone provision has offered farmers the needed financial assistance in this fundamental step in soil conservation.

Many farmers do not take advantage of the program to help lime their acid soils. Some purchased clover seed, to earn their soil building payments, and seeded it on land so acid or so deficient in phosphorus that it could not produce a satisfactory crop.

In order to encourage more effective soil-building programs, more encouragement should be offered for liming.

In order to accomplish this, the following proposals are offered:

1. The soil-building allowances should be increased materially.
2. Where new seedings of legumes are made as a soil building practice, evidence must be offered that the past treatment of the land has been such that the clover or alfalfa has a good chance of producing a satisfactory crop. Standards for these treatments would be prepared by the Agronomy Departments of the states concerned.
3. Encourage more farmers to use limestone as a means of earning soil-building payments by offering some special inducement. This might be done by offering cooperators in the program an opportunity to accept payment in limestone in lieu of check.

The Soil Conservation Service.—The Soil Conservation Service appreciates the value of liming materials in a soil conservation program and its efforts have increased their use in communities where it has worked. It is hoped that the Soil Conservation Service may be able to devise means to further increase the use of liming materials.

J. H. BARRON EARL JONES
J. L. BOATMAN C. M. LINSLEY, *Chairman*

RESOLUTIONS

IN MEMORIUM

THE Committee on Resolutions announces with regret and with a feeling of great loss, not only to the Society but also to their respective families, the deaths of s x agronomists during the past year.

These are Thomas Lyttleton Lyon, Cornell University, Ithaca, N. Y.; Alfred Evan Aldous, Kansas State College, Manhattan, Kansas; John Budd Wentz, Iowa State College, Ames, Iowa; Herman Hamilton Wedgworth, Everglades Experiment Station, Belle Glade, Florida; Robert Marlin Barnette, University of Florida, Gainesville, Florida; and Frederick William Oldenburg, University of Maryland, College Park, Maryland.

ALFRED EVAN ALDOUS

DR. ALFRED EVAN ALDOUS, Professor of Pasture Improvement, Department of Agronomy, Kansas State College, died at his home in Manhattan, Kansas on May 4. He is survived by his wife, Mrs. Coral K. Aldous, and two daughters, Lois Geraldine and Joan.

Dr. Aldous was born near Ogden, Utah on November 18, 1885. In 1916 he married Coral Kerr.

Dr. Aldous was graduated from the Utah Agricultural College in 1910 and entered the U. S. Forest Service immediately upon graduation. In 1911 he took special graduate work in botany and plant ecology at the University of Minnesota. In 1934 he was granted the Ph.D. degree from the University of Nebraska. Previous to coming to Manhattan to assume the direction of the pasture research program in 1926, Dr. Aldous was with the Land Classification Division of the U. S. Geological Survey, and previous to that time had been in range and grazing research with the U. S. Forest Service.

Dr. Aldous made many contributions to our knowledge of pasture improvement, range management and research in the selection and development of pasture grasses. The results of his experimental work have been published in several experiment station bulletins and technical journals. He was outstanding in his profession as a teacher, investigator and leader, and will be greatly missed professionally, not only by Kansas but by his many friends throughout the country.

Dr. Aldous was a member of the American Society of Agronomy, and has served on several committees of the Society. He was also a member of the American Association for the Advancement of Science Sigma Xi, Phi Kappa Phi, Alpha Zeta, and Gamma Sigma Delta.—R. I. THROCKMORTON.

ROBERT MARLIN BARNETTE

DOCTOR ROBERT MARLIN BARNETTE, Chemist at the Agricultural Experiment Station of the University of Florida, was killed instantly on the evening of October 31 while driving alone in his car a few miles north of Gainesville. In the immediate family of his parents Dr. Barnette is survived by three sisters and a brother, all living in South Carolina at the present time. Dr. Barnette was born in Rock Hill, County of York, South Carolina, November 30, 1900. In 1920 he graduated from Clemson College and in 1923 received the Ph.D. degree from the University of New Jersey where he specialized in soil chemistry.

Following his graduation from the New Jersey institution, Dr. Barnette spent a year abroad in travel and study. His study was divided equally between the Rikkslandbouwproefstation in Gröningen, Holland, where he studied under Dr. D. J. Hissink and at the Eidgenossische Technische Hochschule, in Zurich, Switzerland, where he spent much of his time in the laboratories of the late Professor George Wiegner.

Following his return to the United States, Dr. Barnette worked for two years as Assistant Chemist at the Tennessee Agricultural Experiment Station. In 1925 he was appointed Assistant Chemist at the Florida Agricultural Experiment Station, became Associate Chemist in 1929 and Chemist in 1932. At the time of his death he was in charge of the Land Use Division of the Department of Chemistry and Soils.

As indicated by his published works, Dr. Barnette has largely interested himself in the fundamental nutrition of plants especially as influenced by the physical characteristics of the soil environment in which they grow. Having studied with

Wiegner and Hissink in Europe just at the time base exchange phenomena in the soil were beginning to be understood and their importance appreciated, Dr. Barnette became a pioneer worker in this field in Florida and in the Southeast. Throughout his work both organic and inorganic colloids were emphasized and the importance of the rôle of organic matter in the soil in this and other connections repeatedly pointed out.

In the death of Dr. Barnette the American Society of Agronomy and the Soil Science Society of America have lost a keenly discerning and energetic worker. To all who have had personal associations with him and especially to those of us who have been privileged to live and work closely with him there can not but come a deep feeling of loss in the passing of a staunch and ever sympathetic friend.—R. V. ALLISON.

THOMAS LYTTLETON LYON

THE death of Thomas Lyttleton Lyon removed not only one of the founders of the American Society of Agronomy but also the man, who, as much as any other, was responsible for its inception. From the year of its establishment in 1907 until his retirement as head of the Department of Agronomy at Cornell University, he worked earnestly for the success of the Society. Its growing membership and its expanding publications are evidence of the foresight of the men, who in those early days dared with him to launch such a project. Not only was Dr. Lyon president of the Society but for several years he served as its secretary. Later, as an especial evidence of esteem, he was made historian and there is recorded in the January, 1933, number of this JOURNAL a brief history of the Society from his pen.

Dr. Lyon's scientific attainments are so well known that only brief mention of these need be made here. His lysimeter studies, his work on the various phases of soil nitrogen, his rotation and fertilizer experiments and his cereal investigations are outstanding. His published scientific articles are many. His textbooks are noteworthy; the first, "Principles of Soil Management" (with E. O. Fippin), was published in 1908 and his sixth, "The Nature and Properties of Soils", 3rd edition (with H. O. Buckman), appeared in 1937, a few months before his retirement from active duty. His career was a long and busy one.

Thomas Lyttleton Lyon was born in Allegheny County, Pennsylvania on Feb. 17, 1869. His passing occurred on October 7, 1938 at his home in Ithaca, New York where he had resided for thirty-two years. Dr. Lyon prepared for college in the Pittsburgh High School and graduated from Cornell University in 1891. Later he studied with Prof. Tollens at the University of Goettingten and with Prof. Caldwell at Cornell University. He received his Ph.D. degree from the latter institution in 1904.

In 1891 young Lyon accepted a position at the University of Nebraska and served there as instructor in chemistry, assistant chemist and finally as professor of Agriculture until 1906. From 1899 to that date he was also associate director of the Nebraska Agricultural Experiment Station. While in Nebraska he was married to Bertha L. Clark of Lincoln. Two sons added much to the happiness of his married life. In 1906 Dr. Lyon was called to Cornell University by Dean Liberty Hyde Bailey as Professor of Experimental Agronomy and was made head of the Department of Soil Technology in 1912. This was later expanded into a department of agronomy.

Although Dr. Lyon made several notable scientific contributions while at the University of Nebraska, his most valuable work was done at Cornell University.

Caldwell Field, named in honor of his old teacher, Prof. George Chapman Caldwell, was the site of his lysimeter and plat experimentations and other field studies. It was for years the mecca of those interested in such types of investigation. Nothing pleased him more, when health and time permitted, than a trip to "the field", as it was called, with visitors or other friends. Because of his amiable disposition and broad cultural background, Dr. Lyon was an ideal host, genial and delightfully conversant with almost any subject his guests might chance to broach. Many still remember him as he was in those more vigorous days before his waning health began to curtail his outside activities.

Although it is often difficult for colleagues to correctly evaluate the work and influence of their associates, agronomists the country over will agree that the passing of Thomas Lyttleton Lyon was a real loss to scientific agriculture and to soil science especially. His good judgment, his quiet dignified efficiency, his considerate companionship, his high ideals and the soundness of his scientific research mark a man whom it was good to know.—H. O. BUCKMAN.

FREDERICK WILLIAM OLDENBURG

A SEVERE loss was sustained by the Extension Service, by his associates, and by the farmers of Maryland in the passing of Frederick William Oldenburg, who for the last 20 years had been specialist in agronomy. Mr. Oldenburg's death occurred at his home in Hyattsville on January 22, following an automobile accident on November 28, 1937.

His earnest devotion to his work, his untiring efforts, his genial personality, and unfailing loyalty had won for him a place in the hearts of those with whom he came in contact. He was widely known throughout the state and deserves a large share of credit for many important developments in Maryland agriculture. Mr. Oldenburg devoted much of his time in extension work in encouraging farmers to use adapted varieties of seed and to improve the quality of their seed. Several years prior to his death he developed a program, in cooperation with the Soils Department, of giving farmers assistance in their fertility problems by providing facilities for making quick tests and in interpreting the results for them.

His work in extension contributed much in bringing about the increased average yields per acre of field corn and wheat in Maryland over the past decade.

Mr. Oldenburg was born in Wisconsin on December 30, 1873. He was a member of the class of 1899 at the United States Military Academy. In 1902, he graduated from the Oshkosh Normal School at Oshkosh, Wisconsin. He became a teacher and superintendent of schools in various Wisconsin cities and later a member of the faculty at the Iowa State Teachers' College after receiving a degree from the University of Wisconsin in 1915. He was president of the Normal School at Park River, North Dakota, before coming to the University of Maryland in 1917.

Mr. Oldenburg was a member of the Association of Graduates of the United States Military Academy, the Knights of Pythias, and Tau Chapter of Episilon Sigma Phi fraternity. He was secretary of the Maryland Crop Improvement Association, a member of the American Society of Agronomy, Maryland Farm Bureau, and the Hyattsville Horticultural Society.

Surviving Mr. Oldenburg are his wife and three children, Mrs. Waverly W. Webb and Mrs. Dayton Watkins of Hyattsville and Lester Oldenburg of Hyattsville, Maryland. Interment was in Arlington National Cemetery.—JOHN W. MAGRUDER.

Herman Hamilton Wedgworth

HERMAN Hamilton Wedgworth of Belle Glade, Florida, a member of the American Society of Agronomy, died during the evening of October 12, a few hours following severe injuries sustained while supervising construction operations on one of his many agricultural projects in the Everglades area. In his immediate family he is survived by his wife, Ruth Springer Wedgworth, a son and two daughters.

Mr. Wedgworth was born in Mississippi in 1901, received a bachelor's degree from Mississippi Agricultural and Mechanical College and a master's degree from Michigan State College in his chosen field of plant pathology. He served on the Mississippi Plant Board as Inspector, was Instructor in the Department of Plant Pathology at Cornell for two years, was Associate Plant Pathologist on the Mississippi State Plant Board for two years, was Research Assistant in plant pathology at Michigan State College from 1928 to 1930, and in 1936 was appointed Associate Plant Pathologist at the University of Florida and stationed at its Everglades Experiment Station near Belle Glade.

Although a pathologist by training, Mr. Wedgworth quickly developed a thorough appreciation of the important relationship between soil conditions and the normal growth of plants, especially with regard to their resistance to disease. It was in this field that he made his most important contributions while working at the Everglades Experiment Station.

After two and one-half years of faithful and effective work with the State in the Everglades, he left the public service to engage actively in the fascinating agriculture of that great region. Keen of mind and untiring in his work, in five years he rapidly built up a highly diverse project involving more than a thousand acres under cultivation—largely to diverse truck crops, extensive warehouse and packing facilities, cold storage, fertilizer manufacture and others.

In the death of Mr. Wedgworth the Societies with which he had recently become affiliated have lost a member who had passed through a productive period of research in soil and plant science and taken his broad experience and understanding into the field of practical production on a broad scale. The pioneering community in which he worked recognized him as an agricultural and civic leader and will feel the loss in still other ways for many years to come.

During the entire three and one half hours he lived following the accident which crushed and paralyzed his body on one side, his mind was active and the entire time was given to counsel and planning for the future with his wife who was so soon to assume the heavy responsibility for his life work, their extensive farming project and their children. He recognized clearly the approach of death itself and told those at his bedside of that approach.—R. V. Allison.

John Budd Wentz

IN THE passing of Doctor Wentz we who had served with him through a period of years lost a friend whom we had all come increasingly to respect and admire, because of his earnest, sincere, friendly attitude, and his high personal standards of conduct. We have not known a man of whose integrity of character we were more certain—who set high standards for himself and who was willing to give much of himself that others might gain in the most worthwhile endeavors in life. We who were closest to him and knew him best have profited most—our lives have been enriched by our knowledge of him in his daily life of duties well done.

In the passing of Doctor Wentz, Iowa State College lost the services of a man who was respected and admired for his personal accomplishments, both within the college and without, a teacher, and an investigator who was a searcher for the truth. In addition to his regular duties he served faithfully and continuously on important college committees.

Doctor John Budd Wentz passed away on August 24, 1938, at his home, 1023 Brookridge Avenue, Ames, Iowa. He had been ill for several months but continued his work at the college with his usual interest and zeal just as long as he was physically able to do so.

Doctor Wentz was 47 years of age, having been born in Chariton, Iowa, March 4, 1891. He had his undergraduate college training at the North Dakota State College making his home with his uncle, President J. H. Shepperd. He taught agriculture and biology at the South Dakota State Normal School, Spearfish, South Dakota, in 1913–14 and the next year was employed by the U. S. Dept. of Agriculture, before going to Cornell University as a graduate assistant in the fall of 1915. He was granted the master's degree by Cornell in 1916 and the Ph.D. degree in 1928.

He was on the staff of the Maryland State College as professor of agronomy from 1916 to 1921, when he joined the staff of Iowa State College with the rank of associate professor. Doctor Wentz' particular interest during the 17 years that he served on the college staff here was in the field of crop breeding, teaching this subject and directing the research of graduate students in this field. He will be remembered with affection by the large number of graduate students who came under his guidance and to whom he rendered great service. He also was active on genetic research problems with field crops, contributing a large number of research papers reporting his work.

Doctor Wentz was a member of the American Society of Agronomy, the Genetics Association, Association for the Advancement of Science, and the Iowa Academy of Science. In recognition of his productive research Doctor Wentz had been elected to the following honorary societies: Sigma Xi, Alpha Zeta, Phi Kappa Phi, and Gamma Sigma Delta.

Doctor Wentz contributed greatly to the community in which he had made his home. He has always been very active in the Congregational Church, giving long years of service in various official capacities. He also has contributed greatly to the development of better citizens in the future through the Boy Scouts organization and through the Parent-Teacher Association.

Dr. Wentz was united in marriage to Hazel Edna Patterson September 22, 1915, at Spearfish, South Dakota. He is survived by his wife and one son, John Budd, Jr., who is a sophomore in Iowa State College.—F. D. KEIM.

UNADAPTED AND NON-DESCRIPT SEEDS

THE American Society of Agronomy views with concern the present promiscuous interstate shipping of unadapted and non-descript seeds, which often are of unknown variety and may be foul with weed seeds and seed-borne disease organisms. The Society is mindful of the efforts now being made by state and federal seed law enforcement agencies to curb such movements, but also realizes that present laws are inadequate to cope with the situation Therefore, be it resolved

That the Society urge that appropriate steps be taken toward the enactment of adequate seed laws, both state and federal, and that when adequate seed laws are in the statutes that they be fully enforced so as to eliminate such traffic.

Be it further resolved that members of this Society do all in their power to support and cooperate with those now endeavoring to regulate or control the sale of seeds so that the purchaser will obtain only those stocks of seeds which are adapted to his locality.

Also be it resolved that a copy of these resolutions be presented to the Secretary of Agriculture of the United States and to each appropriate seed enforcement official within the separate states, as representing the firm conviction of members of this Society who are charged with the improvenemt and safeguarding of American field crop agriculture through its supplies of seed.

RESEARCH AND EXTENSION IN WEED ERADICATION AND CONTROL

Whereas the weed menace constitutes an enormous tax upon the agriculture of this country and the area infested with noxious weeds in the United States has been approximately doubled every five years, despite all past efforts of control and eradication,

Therefore, be it resolved, that the American Society of Agronomy in conference, assembled in the city of Washington, November 16, 1938, urgently recommend that the Secretary of the United States Department of Agriculture give consideration to the desirability of meeting this menace thru a program of research and extension in order to develop more adequately methods and means for combating noxious weeds.

O. S. AAMODT R. I. THROCKMORTON
M. F. MILLER J. D. LUCKETT, *ex-officio*
F. D. KEIM, *Chairman*

NOMINATING COMMITTEE

Professor A. T. Wiancko presented the report of the Nominating Committee and upon motion the Secretary was instructed to cast a unanimous ballot for Dr. F. J. Alway for Vice-President. Dr. Ralph J. Garber and Dr. F. B. Smith were elected representatives of the Society on the Council of the American Association for the Advancement of Science. Dr. Ralph J. Garber automatically succeeded to the Presidency and Dr. William A. Albrecht automatically succeeded to the Chairmanship of the Soils Section. Dr. F. D. Keim was elected to the Chairmanship of the Crops Section.

Meeting adjourned.

F. B. SMITH, *Secretary*

AGRONOMIC AFFAIRS

MINUTES OF THE CROPS SECTION BUSINESS MEETING, WASHINGTON, D. C., NOVEMBER 17, 1938

A RESOLUTION on the dissemination of unadapted and nondescript seed stocks and a resolution on weed eradication and control were presented by Professor F. D. Keim and, after discussion, were unanimously adopted and referred to the Committee on Resolutions of the Society. (See pages 1071 to 1072.)

The Nominating Committee appointed by Dr. Ide P. Trotter, Chairman of the Crops Section, and comprising H. B. Sprague, *Chairman*, H. H. Laude, and H. C. Rather, presented the following slate of officers for the Section for 1939 which was unanimously adopted: Professor F. D. Keim, *Chairman*, and Dr. H. H. Love and Professor O. W. Dynes, members of the Executive Committee.

The session closed with a showing by Professor Keim of motion pictures of the Fourth Grassland Congress.

OFFICERS OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1939

President, RALPH J. GARBER, U. S. Dept. of Agriculture.
Vice-President, F. J. ALWAY, University of Minnesota.
Chairman, Crops Section, F. D. KEIM, University of Nebraska.
Chairman, Soils Section and President of the Soil Science Society of America, WILLIAM A. ALBRECHT, University of Missouri.
Editor, J. D. LUCKETT, New York Agricultural Experiment Station.
Secretary-Treasurer, G. G. POHLMAN, Agricultural Experiment Station, Morgantown, West Virginia.
Members of the Executive Committee, ex-officio, EMIL TRUOG, University of Wisconsin, and F. D. RICHEY, Ashville, Ohio.

OFFICERS OF THE SOIL SCIENCE SOCIETY OF AMERICA FOR 1939

President, WM. A. ALBRECHT, Columbia, Missouri.
Past President, A. M. O'NEAL, Washington, D. C.
Secretary, W. H. PIERRE, Ames, Iowa.
Treasurer, G. G. POHLMAN, Morgantown, W. Va.
Editor, J. D. LUCKETT, Geneva, New York.

Section I

Chairman, G. B. BODMAN, Berkeley, California
Past Chairman, L. A. RICHARDS, Ames, Iowa
Secretary, J. F. LUTZ, Raleigh, North Carolina

Section II

Chairman, J. W. TIDMORE, Auburn, Alabama
Past Chairman, E. E. DETURK, Urbana, Illinois
Secretary, M. S. ANDERSON, U.S.D.A., Washington, D. C.

Section III

Chairman, A. W. HOFER, Geneva, New York
Past Chairman, N. R. SMITH, U. S. D. A., Washington, D. C.
Secretary, O. H. SEARS, Urbana, Illinois

Section IV

Chairman, J. J. SKINNER, U. S. D. A., Washington, D. C.
Past Chairman, H. J. HARPER, Stillwater, Oklahoma
Secretary, W. H. METZGER, Manhattan, Kansas.

Section V

Chairman, S. S. OBENSHAIN, Blacksburg, Virginia
Past Chairman, W. E. HEARN, U. S. D. A., Washington, D. C.
Secretary, T. M. BUSHNELL, Lafayette, Indiana

Section VI

Chairman, W. L. POWERS, Corvallis, Oregon
Past Chairman, E. A. NORTON, U. S. D. A., Washington, D. C.
Secretary, H. E. MIDDLETON, U. S. D. A., Washington, D. C.

DOCTOR SMITH RESIGNS

IT WAS with deep regret that the Executive Committee accepted the resignation of Dr. F. B. Smith as Secretary-Treasurer of the American Society of Agronomy, effective with the close of the annual meeting in Washington. Pressure of duties in his still comparatively new surroundings at the University of Florida seemed to make it imperative even a year ago that he be relieved of the heavy duties of the Secretary's office. He agreed to see the Society through the past year, however, with the many necessary readjustments that had to be made following the death of Doctor Brown, but again asked to be relieved of his duties with the close of this year's business.

It is common knowledge that Doctor Smith has met exceedingly well all of the varied demands made upon him and the affairs both of the American Society of Agronomy and of the Soil Science Society of America have prospered under his direction. Fortunately, his experience and counsel will still be available to the Society and to his successor.

On behalf of the new Secretary-Treasurer, Dr. G. G. Pohlman, Head of the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, West Virginia, we bespeak the indulgence of all members of the Society while he familiarizes himself with the details of his duties. So much depends upon the efficiency of the Secretary's office in the smooth operation of the affairs of the Society that one is inclined to take many things for granted that actually represent hours of labor and careful attention to infinite detail. The Society is fortunate indeed that a man of Doctor Pohlman's demonstrated efficiency and leadership is willing to assume the obligations and responsibilities of this new office in which the only reward can be the satisfaction of doing a very necessary job in a workmanlike manner.

PRELIMINARY NOTICE CONCERNING THE FOURTH INTERNATIONAL CONGRESS OF SOIL SCIENCE

ATTENTION is hereby called to the fact that the time for the call for papers by the general committees of the International Society of Soil Science for the 1940 meeting of the Society is approaching. The American members of the International Society of Soil Science should give prompt consideration to the submission of titles and abstracts of their anticipated papers to the appropriate section representatives as listed below.

Section I.
Soil Physics—L. D. Baver, Ohio State University, Columbus, O.

Section II.
Soil Chemistry— C. E. Marshall, University of Missouri, Columbia, Mo.

Section III.
Soil Microbiology—Charles Thom, Bureau of Plant Industry, Washington, D. C.

Section IV.
Soil Fertility—W. H. Pierre, Iowa State College, Ames, Iowa

Section V.
Soil Morphology—L. C. Wheeting, State College of Washington, Pullman, Washington

Section VI.
Soil Technology—A. G. McCall, Soil Conservation Service, Washington, D. C.

Any suggestions for symposium subjects should be sent to the general chairman.—W. P. KELLEY, *General Chairman*, Agricultural Experiment Station, Berkeley, California.

SUMMER MEETING OF CORN BELT SECTION

THE CORN BELT SECTION of the American Society of Agronomy will hold its annual summer meeting in Ohio on June 14, 15, and 16, 1939. Tentative plans include an inspection and discussion of the work at Wooster, Columbus, and several of the outlying experiment farms. An invitation has been extended to the Northeastern and Canadian agronomists to meet with the Corn Belt group at that time.

NEWS ITEM

DOCTOR A. J. PIETERS, Principal Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, retired November 30.

Doctor Pieters will be associated with the Greens Section of the U. S. Golf Association, with headquarters in Washington, and will engage in the development of fine turf grasses.

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